SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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OCTOBER 1958—VOL. 30, No. 10

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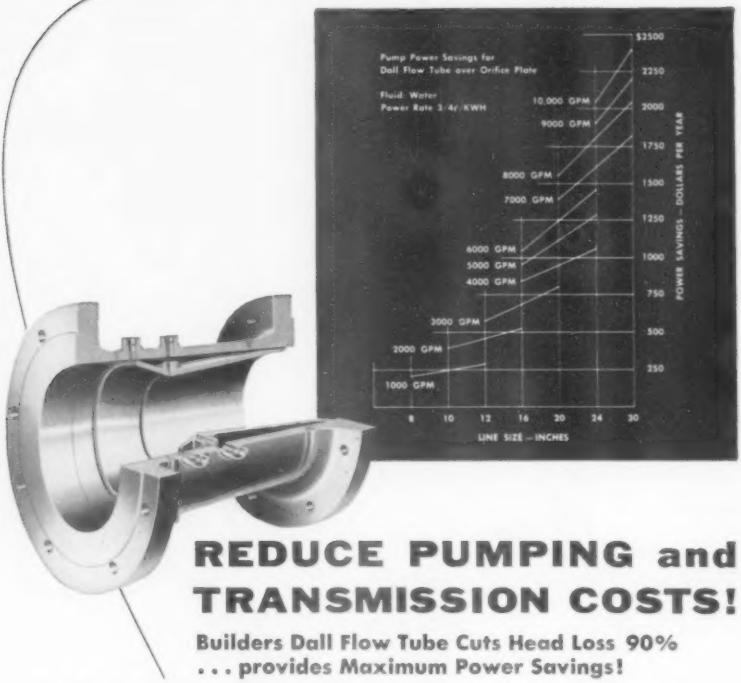

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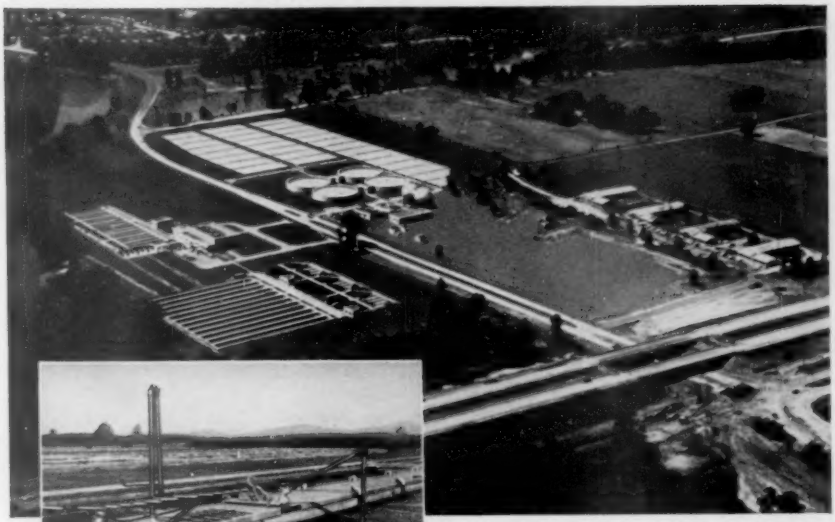

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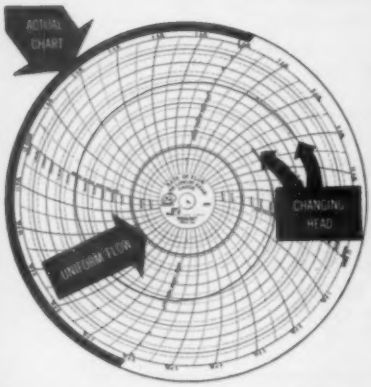

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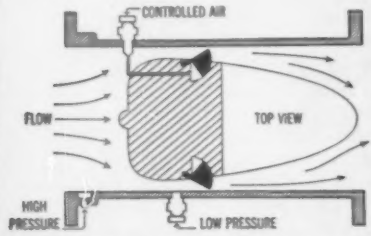

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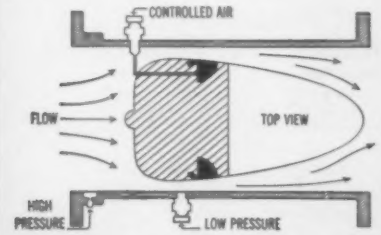

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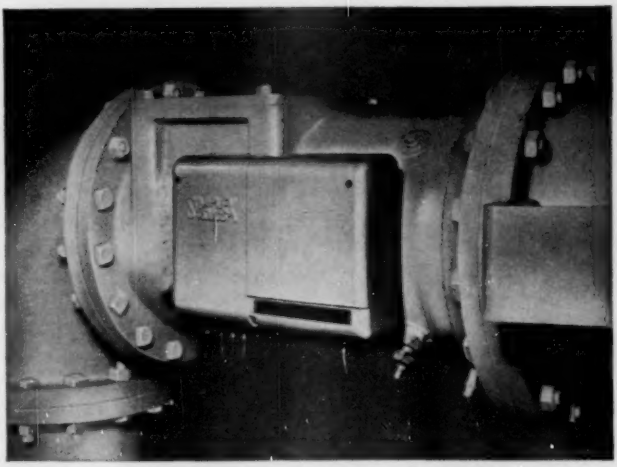

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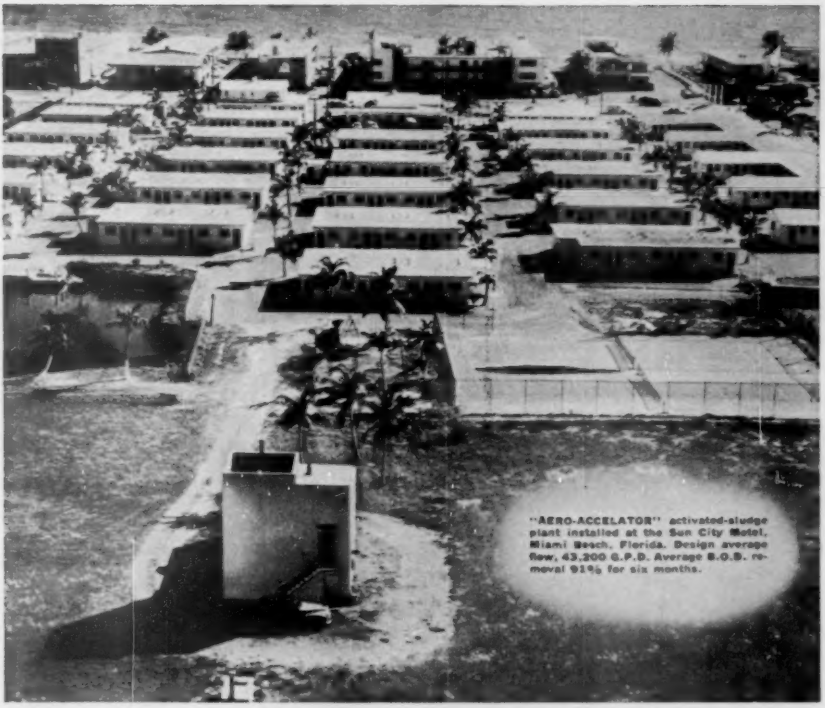
Association	*Place*	*Time*
North Dakota Water and Sewage Works Conf.	Ray Hotel Dickenson, N. Dak.	Oct. 1–3, 1958

THIRTY-FIRST ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
Michigan Sewage and Industrial Wastes Association
Sheraton-Cadillac Hotel, Detroit, Michigan
October 6–9, 1958

Florida Sewage and Industrial Wastes Assn.	Golden Gate Hotel N. Miami Beach, Fla.	Oct. 19–22, 1958
Canadian Institute on Sewage and Sanitation	Chateau Frontenac Quebec City, Que., Can.	Oct. 19–22, 1958
West Virginia Sewage and Industrial Wastes Assn.	Daniel Boone Hotel Charleston, W. Va.	Oct. 22–23, 1958
New England Sewage and Industrial Wastes Assn.	Statler Hilton Hotel Hartford, Conn.	Nov. 5–6, 1958
Nebraska Sewage and Industrial Wastes Assn.	Lincoln Hotel Lincoln, Nebr.	Nov. 6–7, 1958
North Carolina Sewage and Industrial Waste Assn.	Hotel O'Henry Greensboro, N. C.	Nov. 10–12, 1958
South Carolina Water and Sewage Works Assn.	Jefferson Hotel Columbia, N. C.	Nov. 14, 1958
New York Sewage and Industrial Wastes Assn.	Park Sheraton Hotel New York, N. Y.	Jan. 22–23, 1959
Texas Water and Sewage Works Assn.	Texas A & M College College Station, Tex.	Mar. 1–6, 1959
Mississippi Sewage and Industrial Wastes Assn.	Robert E. Lee Hotel Jackson, Miss.	Mar. 6, 1959
New Jersey Sewage and Industrial Wastes Assn.	Traymore Hotel Atlantic City, N. J.	Mar. 11–13, 1959



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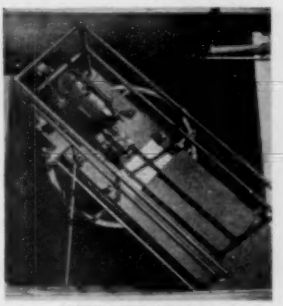
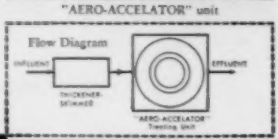
Jan.	.006	187	9.5	94	239	24	90
Feb.	.010	157	13.0	92	409	32	92
Mar.	.005	137	7.0	95	383	28	93
Apr.	.006	211	25.0	88	328	38	89
May	.006	171	9.9	94	222	9	97
June	.008	173	8.0	95	295	32	89



"AERO-ACCELATOR" unit



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4. EXTERNAL LOAD RESISTANCE . . . 6" Class 150 Pipe withstands a crushing load of 17,900 pounds per foot . . . nearly 9 tons.
5. CORROSION RESISTANCE . . . Cast Iron Pipe effectively resists corrosion . . . vital factor in its long life and dependability.
6. TIGHT JOINTS . . . A full range of leak-proof, low cost, easy-to-assemble joints for pipe and fittings are available for all conditions.

THE MAN WHO CHOOSES CAST IRON PIPE TODAY WON'T PAY FOR IT AGAIN TOMORROW!

CAST IRON

Cast Iron Pipe Research Association
Thos. F. Wolfe, Managing Director
Suite 3440, Prudential Plaza, Chicago 1, Ill.

pipe FOR MODERN WATER WORKS

Rodney Hunt gates of tough Everdur withstand bleach-plant acid and pulp-mill wastes

Settling tanks of one of the first industrial waste-treatment plants in the paper industry at the Covington, Va., plant of West Virginia Pulp and Paper Co. Everdur was specified for mixing-chamber gates to resist corrosion by bleach-plant acids and pulp-mill wastes.

One of a pair of mixing-chamber gates fabricated of Everdur, each 48" wide by 54" high. The slide is a sheet of Everdur, reinforced by Everdur angles braze-welded in place. Frame and 2" stem also of Everdur.

Resists corrosion. Sewage treatment and waterworks equipment of Everdur* has been in service without replacement for 20 years and longer.

Toughness. Everdur also possesses high strength and resistance to wear and abrasion —so that engineers can use lighter weight wrought material in their designs.

Readily fabricated. Alloys of Everdur are available for hot or cold working, welding, free machining, forging and casting — and can be obtained in plates, sheets, rods, bars, angles, channels, tees, I-beams, wire, tubes, electrical conduit and casting ingots.

Write for Publication E-11, "Everdur Copper-Silicon Alloys for Sewage Treatment and Waterworks Equipment" — or for technical help in selecting the correct material for your job. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Limited, New Toronto, Ont.

*Reg. U. S. Pat. Off. 57131

EVERDUR Anaconda's family of Copper-Silicon Alloys

MADE BY THE AMERICAN BRASS COMPANY

STRONG · WORKABLE · WELDABLE · CORROSION-RESISTANT

GASLIFTER UNIT

DIGESTER CIRCULATOR-MIXER

INCREASED CAPACITY—GASLIFTER circulated digesters easily handle loadings of 6 lbs. of solids/cu. ft./mo.

BETTER DIGESTION—15 to 20% more gas (methane) per lb. of volatile solids, together with low and uniform volatile acids—all accomplished in single stage digestion at high loading rates.

ELIMINATES SCUM BLANKETS AND GRIT SHOALS—Rapid circulation along roof, walls and bottom disperses grease blanket and prevents loss of capacity due to grit shoaling.

ADAPTABLE TO STANDARD OR HIGH RATE DIGESTION—The GASLIFTER may be applied to either standard or high rate digesters with equally efficient results.

ACCESSIBLE—SPECIALLY DESIGNED LOCKING CHAMBER permits individual inspection and service of stainless GASLIFTER sparging units without dangerous gas loss or digester shutdown.

NO MECHANICAL SHUTDOWNS—GASLIFTER utilizes gas-lift principle and completely avoids mechanical troubles from rag and sewage "string" fouling. Sparjers used to diffuse gas in the eductor tube avoid all orifice troubles.

GASLIFTERS incorporate the patent rights of Joseph Cunetta

Above—Installation at Aurora Sanitary District, Aurora, Illinois serves to illustrate circulation and mixing action achieved with GASLIFTER. Published operating data attests to the resulting increased efficiency.

Walter A. Sperry
Supt., Aurora Sanitary District
Walter E. Deuchler Co., Aurora
Consulting Engineers

Engineers will be interested in Bulletin 25-S-91 for details on GASLIFTERS, and Brochure 25-S-11336 for complete report on GASLIFTER operating results of a full scale plant installation. Write for your copies.

GASLIFTER is a trademark of Walker Process Equipment Inc.

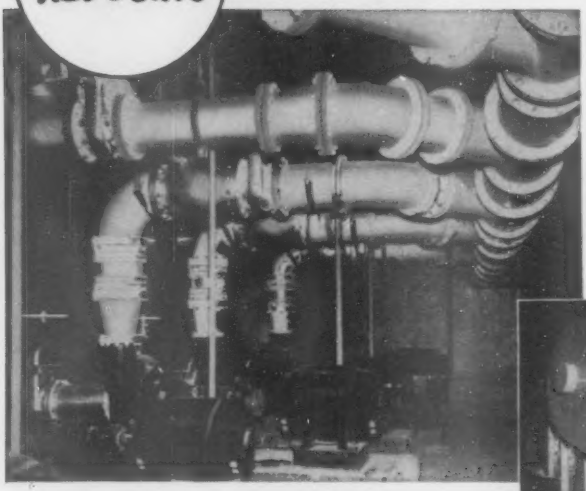
WALKER PROCESS

WALKER PROCESS EQUIPMENT INC.
FACTORY • ENGINEERING OFFICES • LABORATORIES
AURORA, ILLINOIS

CO$T-REDUCING

INERTOL® PAINTS

Specified for Rochester, Minnesota, Sewage Plant



● **Pump Gallery:** Piping and equipment painted with *Glamortex® Enamel*, finest quality alkyd, in color, to assure a long-lasting, fade-resistant finish.

● **Walls and ceilings** throughout this modern plant, like those of the room housing the Link-Belt Grit Collector, are guarded with *Ramuc® Utility Enamel*, chlorinated natural rubber-base. Colorful *Ramuc* is easy to clean, chemical-resistant and won't saponify. It affords top maintenance economy as well as durable protection.

PHOTO COURTESY LINK-BELT COMPANY

Specified by Engineers Toltz, King & Day, Inc., St. Paul, Minnesota, to fully protect this $2,000,000 plant

Since 1937, Inertol coatings have been used by the city of Rochester—world-famous medical center. Like hundreds of municipalities across the country, it has found that Inertol assures long-term protection plus considerable maintenance savings.

Hardness . . . elasticity . . . chemical inertness...beauty—these Inertol qualities explain why the Rochester plant is another 100 per cent Inertol job.

Buy Inertol paints direct from the manufacturer! Shipment within three days from our plant, or from nearby warehouse stocks. For full details about Inertol paints, send for free, comprehensive "Engineers' Painting Guide." Just write us on your firm's letterhead, giving your title.

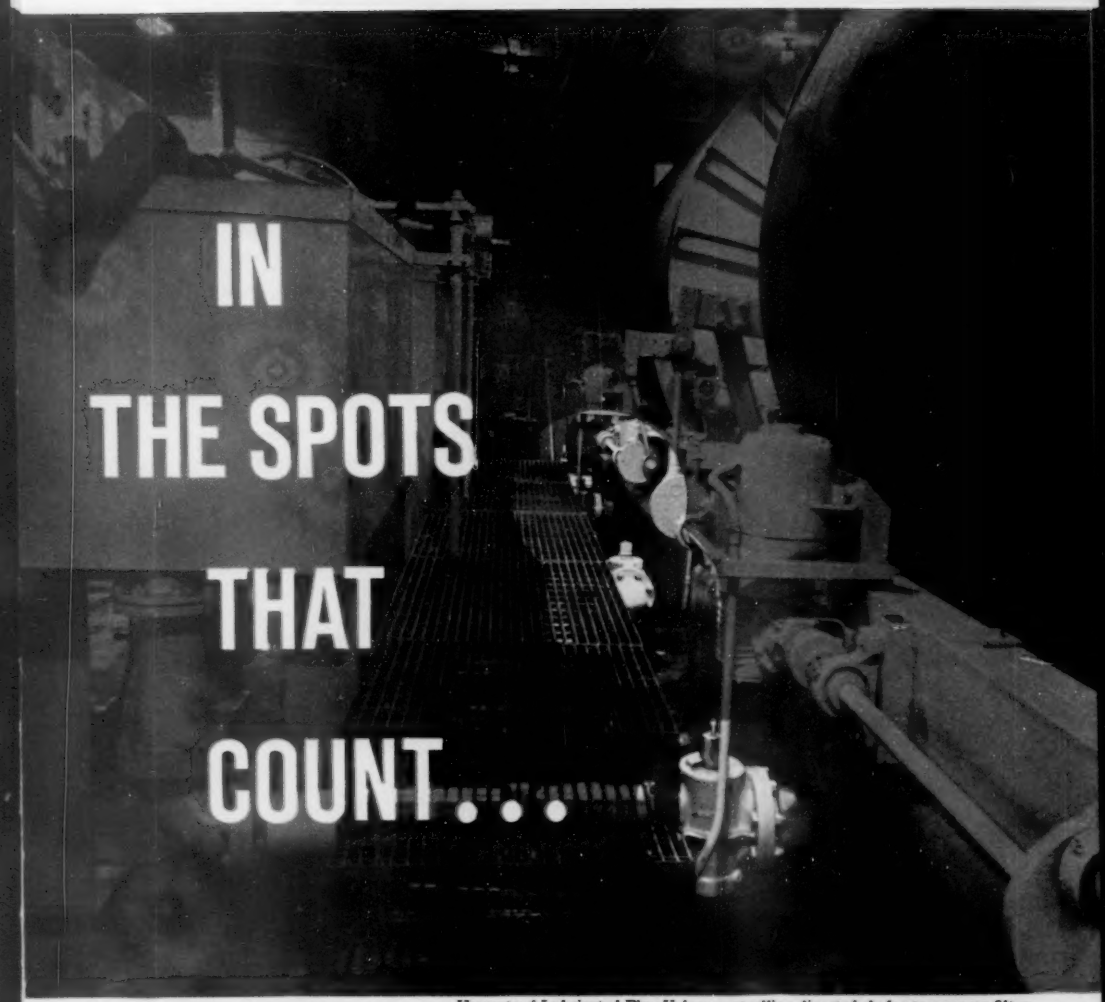
Be sure to inquire about Rustamor,® Inertol's new hygroscopically controlled rust-neutralizing paint.

A Complete Line of Quality Coatings for Sewage Plants and Water Works

Inertol

INERTOL CO., INC.

482 Frelinghuysen Avenue, Newark 12, New Jersey
27H South Park, San Francisco 7, California



Homestead Lubricated Plug Valves controlling digested sludge to vacuum filters.

Sewage plants make important savings in maintenance costs with Homestead Valves

Pump overloading resulting from restricted port area valves is eliminated by the 100% pipe area of Homestead Lubricated Plug Valves.

This, coupled with Homestead's controlled pressurized lubrication and positive chemical seal, results in years of trouble-free, low cost service. Write today for complete information on how Homestead Valves can help you achieve lower maintenance costs.

hv

HOMESTEAD VALVE MANUFACTURING COMPANY
P.O. Box 48 • Coraopolis, Pennsylvania

Please send me catalog on Homestead Lubricated Plug Valves. We are interested in this specific application:.....

.....

Name.....

Street.....

City..... Zone..... State.....

One of two (2) main operating corridors showing individual filter control stations whose modern design permits initiating and carrying out the backwash cycle automatically.

CITY OF DETROIT
Department of Water Supply
NORTHEAST FILTER PLANT & PUMPING STATION
Gerald Remus, Dept. Gen. Mgr.

General Contractors
Bryant & Detweiler, Detroit (Pumping Station & Foundation)
Greve-Sheppard, Wilson & Krog, New York (Filter Bldg.)

Equipment Contractors
Municipal Service Co., Kansas City (Filter Equipment)
Stanley Carter Co., Detroit (Metering Equipment)

A view of the pump controls framed between two of the vertical motors. Enclosed control center contains all instrumentation necessary for monitoring operation of station. Large dial gauges provide continuous indication of station performance.

Plant engineer, George Dehem, inspects an individual filter control station with one of his filter attendants. All filter operation is supervised from this control panel.

ONE SOURCE
ONE RESPONSIBILITY

B-I-F

B-I-F INDUSTRIES
BUILDERS-PROVIDENCE · PROPORTIONEERS · OMEGA

POSITIVE CONTROL OF MATERIALS IN MOTION BIF METERS FEEDERS CONTROLS

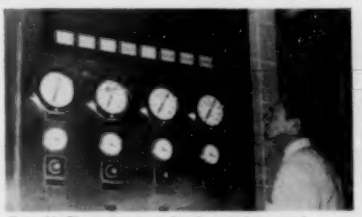
Detroit Equips New Northeast Filter Plant with

INTEGRATED EQUIPMENT OF PROVEN PERFORMANCE FROM "SINGLE RESPONSIBILITY" SOURCE!

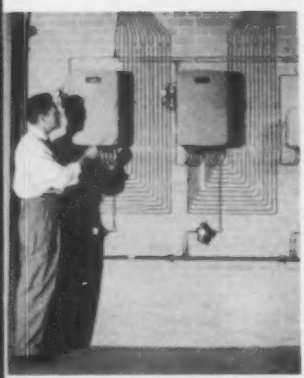
Modern Builders-Providence Controls and Equipment Installed at Detroit's 192,000,000 GPD Water Supply System

Supplying the tremendous water demands of the country's fifth largest municipality is no small task. The complex nature of such an operation requires complete integration of all control equipment . . . for maximum efficiency, operation economy and systems reliability.

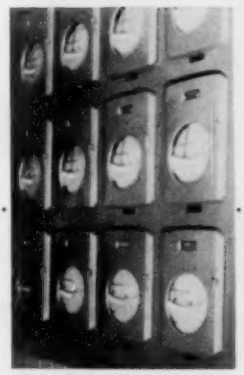
B-I-F Industries as a single, responsible source . . . offering nationwide sales and service through local offices . . . was able to supply the type of equipment (supervisory control, filter control, chemical feeding and related functions) that means immediate and long term savings in time and money. For particulars, write **B-I-F Industries, Inc., 368 Harris Ave., Providence, Rhode Island.**



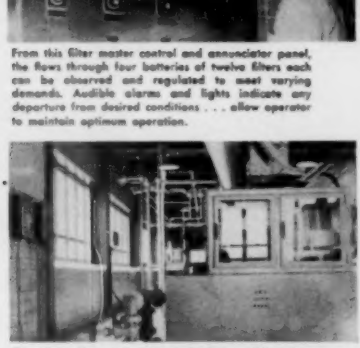
From this filter master control and annunciator panel, the flows through four batteries of twelve filters each can be observed and regulated to meet varying demands. Audible alarms and lights indicate any departure from desired conditions . . . allow operator to maintain optimum operation.



Each of these filter effluent flow summation units totalizes the flows through 12 individual filters and transmits a signal proportional to total flow to instruments located at key locations throughout the plant. In addition, the output of the four summation units is added to obtain total plant flow.



All plant functions for which permanent operating records are required are displayed on this central recorder panel thus permitting operating personnel to note trends of the various functions and departures from normal conditions.



One of the Omega Gravimetric feeders used for alum — others are used for activated carbon. These units provide reliable and accurate proportioning of chemicals to water being treated regardless of plant output variation.

take it

Just what the doctor ordered—an easier day's work. That means Tyton Joint® pipe. This ingenious pipe is a cinch to lay... anywhere, any time... even by inexperienced crews.

No need for bell holes or caulking... no nuts or bolts to fasten. Simply fit a specially designed rubber gasket

U.S. cast iron PIPE

FOR WATER, SEWERAGE AND

easy!

into the bell, and slide in the connecting pipe. The gasket insures a tight, permanent seal. And you can lay Tyton Joint pipe in wet trench or rain.

Call or write for complete details as to how Tyton Joint can save you time, money, trouble.

U. S. PIPE AND FOUNDRY COMPANY
General Office: Birmingham 2, Alabama

A WHOLLY INTEGRATED PRODUCER FROM MINES AND BLAST FURNACES TO FINISHED PIPE

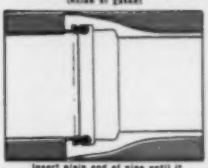
INDUSTRIAL SERVICE

TYTON

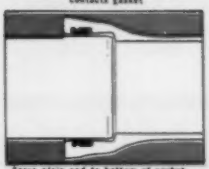
ONLY FOUR SIMPLE ACTIONS

Insert gasket with groove over bead in gasket seat

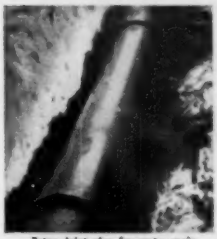
Wipe a film of special lubricant over inside of gasket



Insert plain end of pipe until it contacts gasket

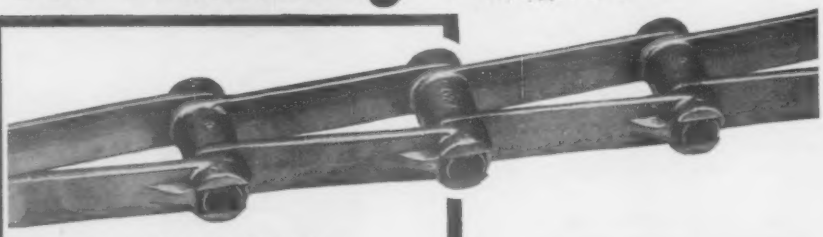


Force plain end to bottom of socket... the job's done!



Tyton Joint pipe for water main extension in Oklahoma.

Webster CHAIN for Handling Wastes

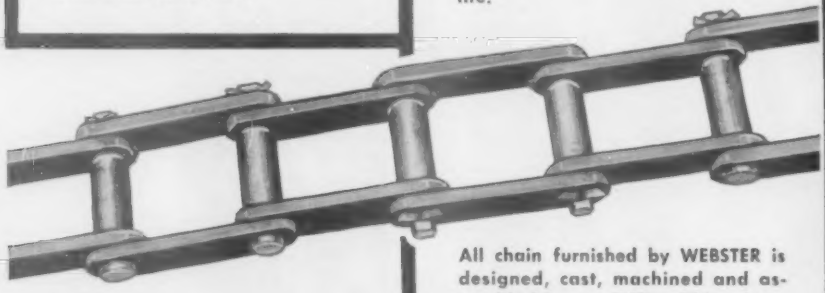


No. 720-S CHAIN

Designed especially for straight-line sludge and grit collectors, where long economical service is important. Pin and cotter construction. Pins have "T" heads securely fitted between lugs cast on side bars. This design prevents the pins from turning in the side bars, thereby distributing the wear over a large area in the barrels of the links. Available in malleable iron or Duramal which is approximately 20% stronger than malleable iron.

No. 111-N CHAIN

Designed for handling abrasive materials such as encountered in grit collectors. The barrels of the links are eliptical in shape to provide more material at point of greatest wear. This feature, together with the close-fitting joints, steel coupler links, and stationary steel pins provide maximum performance, sustained accuracy of pitch, and exceptionally long life.



All chain furnished by WEBSTER is designed, cast, machined and assembled in our Tiffin, Ohio plant.

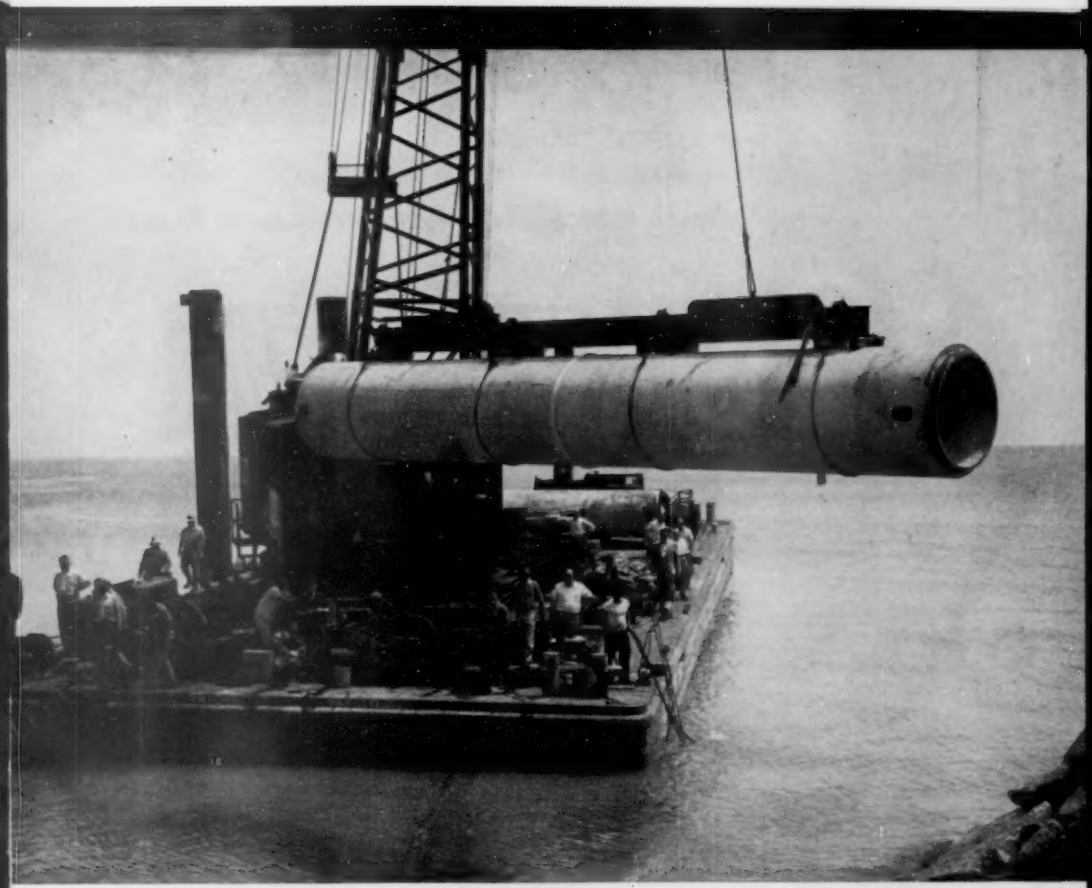
Webster MANUFACTURING, INC.

DEPT. SW-108, TIFFIN, OHIO

BULK MATERIALS HANDLING EQUIPMENT

SINCE WM 1876

Offices in all Principal Cities



UNDERWATER WATER

Concrete Pressure Pipe Offers Many Advantages for Subaqueous Installations

Among these advantages is the ease with which the sections can be assembled. A simple gasket and two lug bolts between the sections provide a permanently water-tight joint. There's no welding . . . no calking. This type of joint also provides flexibility.

Concrete Pressure Pipe is, of course, virtually maintenance free. It has strength, elasticity and cannot corrode. Its smooth interior surface stays that way. It will not tuberculate and initial carrying capacity is sustained.

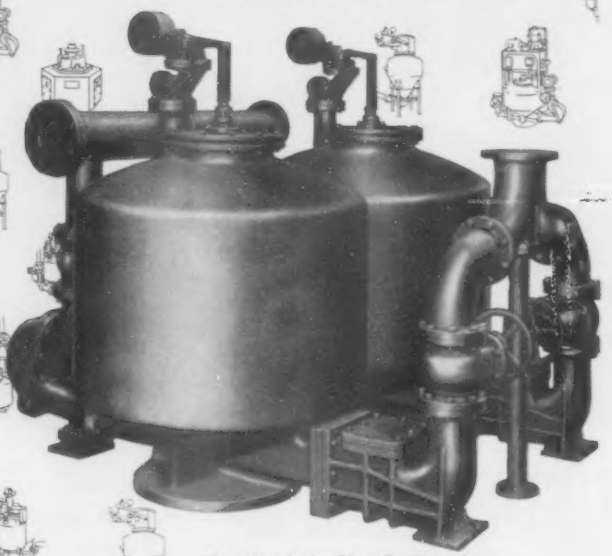
For crossing rivers with water lines or sewer lines; for water intake lines; for outfall lines . . . you will find it advantageous to use permanent Concrete Pressure Pipe.

AMERICAN CONCRETE PRESSURE PIPE ASSOCIATION
228 N. LaSalle Street
Chicago 1, Illinois

WATER FOR GENERATIONS TO COME

there are **NO "GUINEA PIGS"** *among* ***Yeomans Pneumatic Ejectors***

all 212 SIZES and TYPES are JOB PROVED!



Above is a duplex Shone* with mechanical controls—the original pneumatic ejector. The first Shone was installed in 1870. Other Yeomans pneumatic ejectors are: Expelsor®, Packex®, Pneu-Pump, Transporter, and SS Screenings Unit.

There's no risk involved when you specify a Yeomans pneumatic ejector. Chances are your client already knows that it's the most dependable unit he can get . . . and you are able to show him why. Yeomans pneumatic ejectors have exclusive features that can mean the difference between a troublesome 10-year life, and a 25 to 50-year span which is almost maintenance free. In the Yeomans line, also, you can give your client the exact pneumatic ejector required . . . not an "almost model." On your next job, call in a Yeomans representative to show you the difference. He has a slide film which does the job quickly and thoroughly. For your convenience, also, information on Yeomans pneumatic ejectors is carried in Sweet's Catalog.

E-5801

YEOMANS

1999-7 N. Ruby St., Melrose Park, Ill.

WORLD'S LARGEST AND BEST LINE OF PNEUMATIC EJECTORS

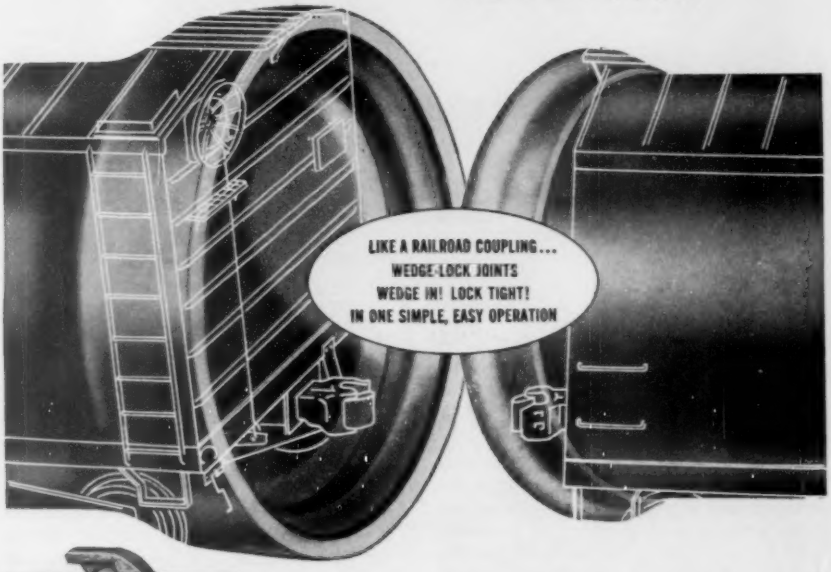
NEW

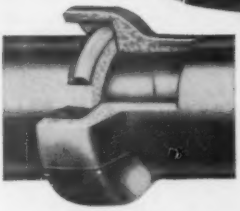
Wedge-Lock* JOINTS

WEDGE IN! LOCK TIGHT!

Stop Infiltration and Roots

Patented Wedge-Lock Joints wedge in and lock tight in one simple, easy operation . . . remain in continuous compression . . . stop infiltration and root penetration . . . keep installation costs down . . . permit strict adherence to design . . . last as long as the world's longest-lasting pipe.





Always specify Vitrified Clay Pipe with Wedge-Lock Plastisol Joints.

Write to listed manufacturers for literature or an actual Wedge-Lock demonstration.

WLC-198-31A

*Patent T. M. Reg. U. S. Pat. Off.

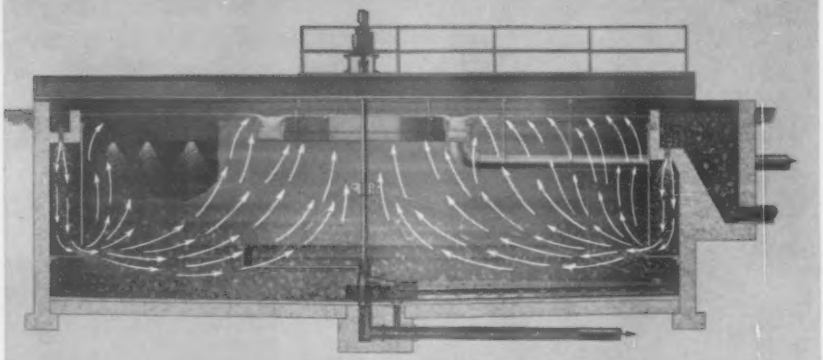
Wedge-Lock CLAY PIPE

THE FACTORY-JOINTED CLAY PIPE AVAILABLE NATIONALLY FROM LOCAL MANUFACTURERS

Order Wedge-Lock from any of these Vitrified Clay Pipe Manufacturers

Cannelton Sewer Pipe Company, Cannelton, Ind.
Clay City Pipe Company, Uhrichsville, Ohio
The Evans Pipe Co., Uhrichsville, O.
Gladding, McBean & Co., Los Angeles 54, Calif. (Sold under trade name, "SPEED-SEAL")
The Logan Clay Products Company, Logan, Ohio
Ocanee Clay Products Company, Milledgeville, Ga.
Pacific Clay Products, Los Angeles 54, Calif.
Pine Hall Brick & Pipe Company, Winston-Salem, N.C.
Pomona Terra-Cotta Company, Greensboro, N.C.
The Robinson Clay Product Company, Akron 9, Ohio
Graff-Kittanning Clay Products Company, Worthington, Pa.
Superior Clay Corporation, Uhrichsville, Ohio
The Stillwater Clay Products Company, Cleveland 16, Ohio

The new REX Rim-Flo Clarifier



Cutaway view of Rex Rim-Flo.

Simplified cutaway view of Rex Rim-Flo illustrating flow patterns.

A NEW HYDRAULIC PRINCIPLE FOR...

- Maximum Hydraulic Efficiency
- Maximum Use of Tank Volume
- Optimum Settling Conditions
- Greatly Increased Capacity
- Simple Scum Removal

IN CIRCULAR TANKS

The unique thoroughly proven hydraulic principle of the Rim-Flo introduces the influent into a circular feed channel entirely around the periphery of the tank. The channel is of uniform width, but the depth gradually decreases from the deepest point at the influent point to the shallowest at the extreme end of the circle.

Properly sized ports are correctly spaced in the floor of the feed channel. Tapered-channel cross section and spaced ports assure a uniform forward-flow velocity in the channel. This prevents any settling out of solids in the channel and assures transportation of all scum to the end of the channel for collection.

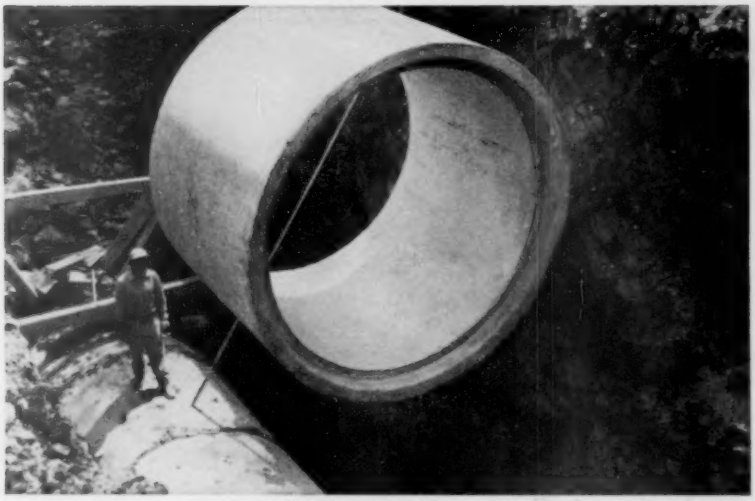
The ports direct the flow downward into the tank between the tank wall and a vertical skirt. The flow approaching the tank bottom is at an extremely low velocity and is directed into the main body of the tank. Solids promptly drop out of suspension onto the tank floor. The flow is directed gently upwards to a central effluent trough.

Rex Rim-Flo is the practical economical solution to the problem of outmoded or overloaded circular settling tanks. Rim-Flo can be adapted to existing circular tanks of practically any size.

For additional information on Rex Rim-Flo or any of the other *plus value* Rex Equipment, write CHAIN Belt Company, 4606 W. Greenfield Ave., Milwaukee 1, Wisconsin.

CHAIN BELT

Milwaukee 1, Wisconsin



Section of 90" concrete pipe is swung into place easily and quickly

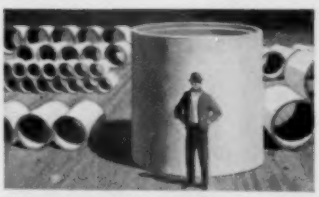
For Chicago's newest sewers . . .

concrete pipe provides maximum strength, greater capacity!

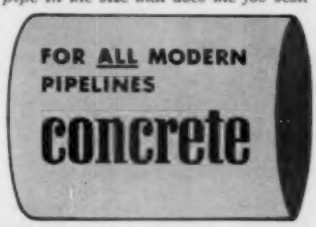
To alleviate street and basement flooding, Chicago is carrying out a multi-million dollar enlargement of its combined sewer system.

On the new Roscoe Street section, 12,500 feet of concrete pipe, 36" through 90" I.D., was used. Placed deep underground—an average of 27 feet for the 90" size—the pipe carries backfill and traffic load without further support. (A real time and economy advantage, too!) And resistance of the pipe to the overburden will increase because concrete gains strength year by year.

And maximum hydraulic capacity is provided by the smooth inner surface of concrete pipe. It resists abrasive wear. Concrete sewers, too, ensure minimum infiltration and leakage. Match all this with moderate first cost and you see why concrete pipe has a long record of solving difficult sewer problems for hundreds of municipalities. Write for free literature, "*Concrete Sewers*," distributed only in the U.S. and Canada.



Wide size range *lets you choose concrete pipe in the size that does the job best.*



PORTLAND CEMENT ASSOCIATION
Dept. 10-76, 33 West Grand Ave., Chicago 10, Ill.
A national organization to improve and extend the uses of concrete

here's what "out of sight out of mind" does to a water main

"Out of sight—out of mind" can be a mighty expensive philosophy in any water distribution system. The above unretouched photograph proves this point. It shows a badly tuberculated *eight inch* main whose *inside diameter was reduced to an average of almost 4.5 inches.* Resultant higher pumping costs with reduced pressure and carrying capacity make it costly to tolerate such conditions. That is why the savings effected in reduced pumping costs frequently pay for the *low cost* of National water main cleaning.

Since there's never a charge or obligation to inspect your mains, *call National now!*

Call in National today!

NATIONAL WATER MAIN CLEANING COMPANY

50 Church Street • New York, N. Y.

ATLANTA 3, GA., 333 Candler Building • BERKELEY, CALIF., 920 Grayson Street • BOSTON 15, MASS., 115 Peterboro Street • CHARLOTTE, N. C., 533 Hollis Road • CHICAGO, ILL., 8 So. Dearborn Street • DECATUR, GA., P. O. Box 385 • EL MONTE, CALIF., 2024 Merced Avenue • FLANDEAU, S. D., 315 N. Crescent Street • KANSAS CITY, MO. 3707 Madison Avenue • MINNEAPOLIS, MINN. 200 Lumber Exchange Building • OMAHA, NEBR., 510 Standard Oil Bldg. • RICHMOND 21, VA., 2910 W. Clay Street • SALT LAKE CITY, UTAH, 502 West 3rd Street • SIGNAL MOUNTAIN, TENN., 204 Slayton Street • VILLA PARK, ILL., 424 S. Yale Avenue • MONTREAL, CANADA, 7445 Chester Avenue • WINNIPEG, MANITOBA, 576 Wall Street • BOGOTA, COLOMBIA, Apartado de Correos #5 • SAN JUAN 10, PUERTO RICO, Manquinaria, Apartado 2184 • LIMA, PERU, Bolivar 441-A, Maraft • CARACAS, VENEZUELA, Apartado 561 • HAVANA, CUBA, P. O. Box 531 • OSLO, NORWAY, Radhusgaten 30

CORROSION YOUR PROBLEM?

How to specify the degree of protection you need

With Armco Sewer Structures you can select the degree of corrosion protection needed for each installation. And you pay only for the protection you need.

Choose the kind of Armco Sewer Pipe that meets your needs:

- **Galvanized corrugated metal pipe . . . normal sewer conditions**
- **Asphalt-coated pipe . . . corrosive conditions**
- **PAVED-INVERT® . . . resists erosion and corrosion in the invert**
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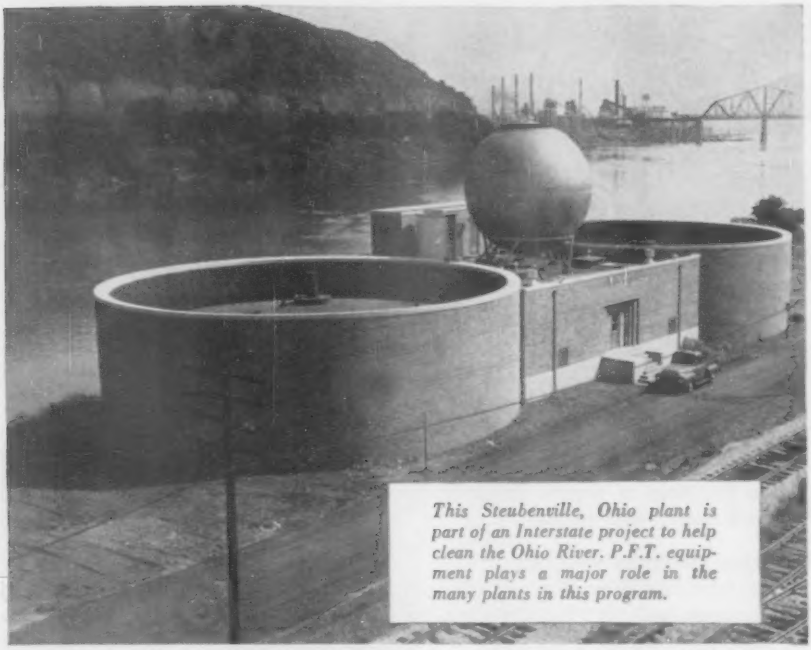

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SEWAGE AND INDUSTRIAL WASTES

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Sewage Works

AN EVALUATION OF STABILIZATION POND LITERATURE

By George P. Fitzgerald and Gerard A. Rohlich

Laboratories of Hydraulic and Sanitary Engineering, University of Wisconsin, Madison, Wis.

A number of articles have described the history of the use of stabilization ponds to treat sewage (10)(21)(32)(42)(43)(55)(56). The function of a sewage oxidation pond can be considered to be multiple. The pond can act as a reservoir to equalize the effects of peak loads on a sewage treatment plant, dilute concentrated sewage, provide, as well as act as, an additional settling basin for treatment. The treatment the pond accomplishes is much greater than could be calculated on a purely settling basin function, however, because algae can thrive on the nutrients in the sewage and, in the process of photosynthesis, produce oxygen. The oxygen produced by the algae is available for maintaining aerobic bacterial decomposition of sewage and the prevention of odors.

Although sewage ponds have been well known in Asia for centuries (42), data on their performance have been found only for the last 50 years, the earliest available data being from various ponds in Germany where valuable crops of fish were grown in sewage ponds (32)(42). These data, as well as some from Australia and the United States, indicate that the use of ponds for sewage purification is a practical procedure where the proper physical environment allows for such construction.

Effectiveness in Lowering BOD

Data on the lowering of the BOD of sewage by passing it through ponds are reported by a number of workers (4) (12) (20) (27) (34) (37) (41)(43) (46)(48)(54)(71)(76), with changes of from 370 to 37 ppm BOD by 108-day detention (20), and from 158 to 20 ppm BOD with 8.7-day detention (76). The average values quoted (Table I) indicate that 150 ppm of BOD could be lowered to approximately 20 ppm by passing through a pond, with a detention time of about 15 days, having the proper environmental factors such as light, temperature, and absence of toxic materials.

The relationship between algae and standard BOD measurements has been discussed by a number of workers (3) (4) (6) (10) (36) (37) (43) (51) (55) (65) It is generally agreed that although the total organic matter in an oxidation pond effluent may be appreciable due to the algal cells, this organic matter does not produce obnoxious conditions below the outfall as does an equivalent concentration of organic matter from sewage. A number of workers (22) (37) (41) (43) (51) (65) believe that the algae in the effluents of ponds will exert a considerable BOD in the receiving streams. The data of Malchow-Moeller *et al.* (37), and Merz *et al.* (41) lend support

TABLE I.—Effectiveness of Sewage Oxidation Ponds for BOD and Bacteria Reductions

Pond Location	BOD (ppm)		Bacteria (per ml)				Ref.
			General		Coliform		
	Sewage	Pond Effl.	Sewage	Effl.	Sewage	Effl.	
College Station, Tex.	370	37	—	—	—	—	20
Killeen, Tex.	91	16	—	—	—	—	43
Shoemaker, Calif.[1]	143	34	—	—	10,000	1.0	46
Melbourne, Australia[2]	530	20	—	—	250,000	350	55
Fuglebjerg, Denmark[3]	148	11	—	—	24,000	33	37
Lund, Sweden[4]	158	20	3,500,000	17,000	100,000	30	76
Munich, Germany	—	—	840,000	2,500	95,000	50	32
Essen-Bredeny, Germany	—	—	—	—	280,000	5,000	40
Santa Rosa, Calif.[5]	93	5.9	—	—	620,000	6,200	4
Santa Rosa, Calif.[6]	57	26	—	—	620,000	600	4

[1] Four ponds in series; total volume 300 acre-ft; average detention time (total) = 26 days.
[2] Anaerobic lagoons followed by aerobic lagoons; BOD of effluent on filtered sample.
[3] Anaerobic lagoons followed by aerobic lagoons; BOD of effluent on filtered sample. Detention times, anaerobic portion 6.7 days, aerobic portion 8.6 days.
[4] Four ponds in series; total detention time = 16.5 days.
[5] Data of March 15, 1955.
[6] Data of May 3, 1955.

to this theory. However, data presented by a number of other workers (4) (10) (36) (43) (48) (51) (65) indicate that despite great increases in the suspended solids concentration and decreases in the ammonia nitrogen contents, the BOD levels changed very little, or even decreased.

Loading

The proper loading of stabilization ponds is obviously important because any purification system can become overloaded. In Europe, the general figure of 1 acre per 1,000 population is considered a safe limit, but loadings as high as 1,800 people per acre have given satisfactory treatment (16). In North Dakota, where ponds freeze over in winter, 10 acres per 1,000 population is suggested, or the capacity of the ponds should be 200 times the daily flow (75).

Other measures of loading are suggested, such as the pounds of BOD per acre. In the National Research Council summary (47) the ponds studied had a loading of 25 to 50 lb/acre-ft per day and satisfactory results were obtained. Detention periods were in the order of 20 to 30 days. Parker *et al.* (55) made a study of loadings on performance of ponds in Australia and found loadings up to 67 lb BOD per acre per day resulted in 90 to 100 per cent purification. Loadings above these values resulted in diminished removal, loadings of 105 to 120 lb per day/acre resulting in only 80 to 85 lb per day/acre removal. They suggest a load of 70 lb per day/acre for general use. However, Sampson (59), at Oceanside, Calif., found that approximately 45 lb BOD per acre per day was the load limit for good treatment for his pond. It is obvious, therefore, that only vague generalizations can be made as far as the loading of ponds is concerned, because the differences in ponds, types of sewage, detention times, and local environmental factors influence the effectiveness of sewage ponds.

Algae

The relation of algae to the process of BOD removal in ponds has been investigated (4) (26) (48) (51) (54)

(71). Certain of the algae which grow in ponds, especially *Chlorella*, are capable of growth in the dark with organic compounds (4) (43) (65). However, numerous experiments have shown that neither *Chlorella* nor other common pond algae (*Scenedesmus, Chlamydomonas, Ankistrodesmus*) can grow oxidatively on sewage in the dark, so it must be concluded that the oxidation of organic matter in sewage is carried out by bacteria and that algae provide oxygen for continued bacterial oxidation (4).

Inasmuch as the growth of algae is controlled by temperature to some extent, the use of oxidation ponds in winter has been questioned. However, it has been found that the general efficiency of the ponds for BOD removal is not greatly affected by temperature (4) (11) (20) (37) (48) (55) (71)(75). Studies in Denmark (37) and in North Dakota (75) have indicated that frozen ponds gave satisfactory treatment (13 and 18 ppm BOD in effluent of ponds in January of 1953 and 1954, respectively, in Denmark).

Oswald *et al.* (54) discussed the relationship between depth, detention time, and BOD removal, concluding that the permissible loading factor is larger in summer than in winter; principally because the amount of light energy is greater, the light strikes the surface more directly, and the temperature is more favorable in summer. Towne *et al.* (71) and Neel and Hopkins (48) agree that BOD removals are greatest during seasons of greatest plankton productivity, but there was little tendency for the BOD removal to vary up and down with the plankton density during most seasons.

Other Factors

There has been a limited amount of quantitative data on the effect of some of the other physical factors that might influence the efficiency of oxidation ponds as far as BOD removal is concerned. It is difficult to make any correlation between detention time and BOD removal, because few reports mention ponds run on an experimental basis with this factor varied.

The Australian report (55) indicates that detention periods in an anaerobic lagoon (first lagoon in a series) should not be more than five days, as the BOD removal decreased with increased detention time. On aerobic lagoon studies by these workers there was no effect on the BOD of the filtered effluent with a variation in detention time of from 21.4 to 10.7 days. This variation was accomplished by decreasing the depth from 3 to 1½ ft in the aerobic lagoons.

Allen (4) states that the large ponds with long detention times which are in use at present are systems which require little control to function effectively, but are not as efficient as small shallow ponds designed for more effective utilization of sunlight by algae. However, ponds designed for only algal growth will be more sensitive to changes in environmental conditions (such as very high temperatures during the daytime) (66) and will require a much greater degree of control (4).

Oswald *et al.* (54) maintained that the loading factor is lower for a deep pond (36 in.) than for a shallow pond (18 in.), because the average light intensity is less throughout a larger fraction of the volume of a deep pond; but Merz *et al.* (41) defend the use of ponds with a 9-ft depth. Depths of from 3 to 5 ft are normally considered optimum (66)(75).

Recirculation has been shown to increase BOD removal only to a small degree, but does aid in increasing the photosynthetic efficiency of the ponds (27). Similarly, light periodicity (percentage of a 24-hr period that light is continuously applied to a culture) of between 20 and 100 per cent has little effect on the per cent BOD

removal (27). It was shown that with 40 per cent or more light periodicity, the algae present produced 3 to 5 times the amount of oxygen required to satisfy the sewage BOD (27).

Effectiveness in Lowering Bacterial Counts

A number of studies have been made on the lowering of bacterial counts in sewage by the action of oxidation ponds (4)(10)(12)(21)(32)(34)(37)(40)(41)(48)(62)(71)(74). In nearly all instances the bacterial counts have been lowered to less than 1 per cent of the original concentration. The *E. coli* counts have generally been reduced from several hundred thousand to less than 100 per ml, and one case has been reported (21) where typhoid bacteria were reduced from 41 per ml to negative results (see Table I).

Caldwell (10) states that the efficiency of ponds in removing coliform bacteria is believed due to liberation of substances toxic to bacteria by the algae. However, Oswald and Gotaas (51) stated that no specific anti-coliform activity can be credited to the algae in the cultures they tested. Towne *et al.* (71) point out that reductions in bacterial numbers at different seasons were not appreciably different, despite variations in the algae content.

Another theory (66) is that the long storage with settling and extreme competition are responsible for reductions in coliform bacteria in ponds. There might be additional effects on the bacteria in an oxidation pond because of the high oxygen levels produced and because the pH of the water frequently goes as high as 9.0 to 9.5 during the daytime due to the absorption of the carbon dioxide in the water by the algae (10)(54).

Ellison and Smith (14) questioned the advisability of allowing wild animals and fowl to have access to sewage ponds, because they may spread sewage-borne diseases to unpolluted waters. This is a very important point. The fact that in Europe and Asia sewage is purposely added to fish ponds as direct feed as well as fertilizer, and the fish are then eaten directly, might cause one to minimize the danger of pollution of waters by such means as Ellison and Smith pointed out. However, more detailed information should be available concerning this subject before any conclusions are drawn.

Effectiveness in Removing Nutrients

Data obtained as early as 1911 (32) indicate that considerable amounts of plant nutrients are removed from sewage by the action of oxidation ponds. This is a natural process, as the algae in the ponds must absorb the nutrients essential for growth before growth can take place (58). Very few nutrients are lost from ponds but they are removed from solution and concentrated in the algal cells. Many references mention changes in the chemical composition of sewage as it passes through ponds (4)(10)(12)(32)(37)(40)(41)(43)(46)(48)(54)(55)(58)(71)(76), the main changes recorded being the reduction of ammonia-nitrogen from 15 or 40 ppm to less than 2 ppm in the pond effluent. Along with the 75 to 90 per cent reductions of the ammonia-nitrogen, up to 60 per cent of the organic-nitrogen is removed from solution. Nitrate- and nitrite-nitrogen may increase, but the amounts present are normally insignificant compared to the ammonia-nitrogen (10).

Phosphorus levels were reduced by 96 per cent (40). Most of this reduction is probably due to precipitation caused by the increased pH of the ponds rather than to absorption by the algae. Potassium is reduced by about 10 to 20 per cent (40). Changes in the chloride concentrations as sewage passes through ponds are not con-

sistent, sometimes increasing (55) and other times decreasing (12)(32). In general, it can be assumed that the algae will remove from solution the nutrients required for growth, which might approach 400 mg dry algae per liter of sewage, plus what might be called a "luxury" consumption of certain of the nutrient factors (see Tables II, III, and IV).

It is obvious that under conditions not favorable for algal development, the nutrient removal efficiency of ponds will be decreased. This may occur when ponds are overloaded, as the experience in Denmark when dunghill drainage entered the pond system and the ammonia-nitrogen was only reduced to 16 ppm, whereas the average pond effluent had 6.0 ppm am-

TABLE II.—Nutrient Composition of Sewage (as ppm)

Location	5-Day BOD	C	H	Nitrogen					Sol. P	K	Mg	Ca	Ref.
				Tot.	NH_3	NO_3	NO_2	Org.					
San Francisco, Calif.	120	91	14	24.6	11.8	0	tr	12.5	8	15	9	24	26
Fuglebjerg, Denmark	148	—	—	25	16	—	—	—	—	—	—	—	37
Lund, Sweden	158	—	—	40.6	—	—	—	—	2.88	12.8	—	—	76
Munich, Germany	—	—	—	—	15	3.5	tr	—	—	—	—	—	32
Killeen, Tex.	91	—	—	—	14	0.1	0.1	—	—	—	—	—	43
Shoemaker, Calif.	170	—	—	—	17	0	0.08	—	—	—	—	—	46
Melbourne, Australia	530	—	—	—	32	0	0	41.7	—	—	—	—	55
Dortmund, Germany	—	—	—	—	39.95	0.20	—	10.65	6.4	—	12.8	—	79
Essen-Bredeny, Germany	—	—	—	20–30	7–8	0.001	—	—	1–2	36–44	—	—	40*
Austin, Tex.	310	—	—	53.9	31.5	—	—	22.4	6.8	—	—	—	21
Madison, Wis.	193	—	—	—	19.3	—	—	10.9	—	—	—	—	2†
Plant effluent	22	—	—	19.9	13.2	3.8	0.3	2.6	5.7	—	—	—	2‡
Richmond, Calif.	—	176	—	50	—	—	—	—	11	14	22	17	4
Concord, Calif.	—	66	17	22	—	—	—	—	13	13	58	40	65
Contra Costa, Calif.	—	101	—	36	—	—	—	—	6	—	—	—	4

* Range of values. † 1950–54 average. ‡ 1950–53 average.

TABLE III.—Chemical Composition of Sewage-Grown Algae (% of Dry Weight)

Species	C	H	N	P	K	Ca	Mg	Ash	Ref.
*Euglena gracilis**	44.8	6.39	4.03	1.88	0.38	1.54	0.30	10.9	52
Chlorella pyrenoidosa†	49.1	7.06	2.91	1.28	1.31	1.85	0.29	7.48	52

Species	Ash	Org. Sub.	Crude Prot.	N	Lipide	Sol. Carbohydrate	Chlorophyll	Ref.
Scenedesmus obliquus	12.3	87.7	32.1	5.1	14.2	17.9	2.1	40

* Analysis of algae at time slightly past optimum growth phase.
† Analysis of algae at time grossly past optimum growth phase.

TABLE IV.—Effectiveness of Sewage Ponds in Nutrient Removal (Summer Values, ppm)

Location	NH_3-N		Organic-N		NO_2-N		NO_3-N		Soluble P		Ref.
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Calistoga, Calif.	3.4	0.9	—	—	0	0.7	0	0.02	—	—	10*
Bergedorf, Germany	25.3	2.3	—	—	—	—	15.5	11.1	—	—	12
Essen-Bredeny, Germany	15	2	—	—	1.5	0	1.0	0	—	—	40†
Killeen, Tex.	14	0.5	—	—	—	—	—	—	—	—	43*
Fuglebjerg, Denmark	16	6	—	—	—	—	—	—	—	—	37*
Shoemaker, Calif.	15	1	—	—	0	0.04	0.08	0.12	—	—	10*
Munich, Germany	15	0.5	—	—	3.5	1.8	tr	tr	—	—	32
Melbourne, Australia	32	16	41.7	6.3	—	—	—	—	—	—	55*
Dortmund, Germany	39.95	1.29	10.65	3.47	0.20	7.24	—	—	6.4	tr	79*
Moscow, USSR	54.5	5.9	—	—	tr	tr	tr	tr	—	—	38*

* Multiple ponds. † NH_3-N and organic-N combined.

monia-nitrogen (37). Another report indicated that a pond in California might have been suffering from a nitrogen deficiency, because when sewage digester supernatant containing 300 ppm ammonia-nitrogen was added to the pond it appeared to cause the most healthy period of the pond to date (59).

Inasmuch as the optimum temperature for growth of most algae appears to be between 15 and 30° C (25)(27)(51), temperatures below these values would be expected to reduce the efficiency of the ponds as far as nturient removal is concerned. As an illustration, the average ammonia concentration from four oxidation ponds reported on by Caldwell (10) was 12.5 ppm during the winter months, whereas the average summer concentration was less than 1.0 ppm. Oswald *et al.* (54) point out how the available light may be as important a factor as temperature when dealing with algae in ponds.

Although considerable data are available on increasing the yield of algae in sewage by supplementing the carbon dioxide content (4)(26)(51)(53), only limited data are available on nutrient absorption as influenced by added carbon dioxide. Allen (4) found that the recovery of sewage nitrogen in the form of algal cells was more efficient when CO_2 was supplied, even though the nitrogen concentration in the cells was lower, the concentration of nitrogen being 2.3 and 2.6 per cent in cells without added CO_2 and 1.4 and 1.3 per cent when 5 per cent CO_2 in air was bubbled through sewage cultures of *Scenedesmus* and *Chlamydomonas*, respectively. This effect may be the result of the presence of more cellular material at the time of analysis in the sewage receiving additional CO_2.

Gerloff and Skoog (19) have reported that the nitrogen and phosphorus content of a blue-green alga decreases as the culture ages (8.93 to 3.77 per cent N and 0.83 to 0.34 per cent P over 20 days of growth). Allen (4) also found that the amount of phosphorus left in solution was less when CO_2 was added to sewage cultures of *Scenedesmus* (1.2 ppm P in supernatant without CO_2 and 0.3 ppm P in the supernatant of sewage cultures with added CO_2).

Growth of Algae in Sewage Ponds

The algae found in sewage ponds have been listed (37)(41)(43)(48)(65) and a few quantitative studies have been made (4)(37)(41)(43)(65)(74). The general data indicate that there is no correlation between which species become dominant in a pond and the geographical location of the pond (43)(65)(67); the degree of BOD loading (4)(43); the degree of pretreatment given the sewage, ranging from none to complete (primary settling, trickling filter, and secondary settling) (4)(67); or the type of pretreatment (67).

In the same pond there might be a qualitatively different population at different sections of the pond. Vaas (74) reported that in a sewage pond in Batavia a dense crop of plankton consisted chiefly of diatoms near the sewage inlet, and diatoms, protococcales, volvocales, and zooplankton near the outlet.

Variable Species

The major variations in algae of waste-water ponds, both qualitative and quantitative, occur as seasonal variations (25) (26) (40) (48) (65). Neel and Hopkins (48) found that there seemed to be a seasonal variation in algal dominance, plus an almost unfailing appearance of *Chlamydomonas* after each anaerobic period. An alga that will remain in a logarithmic growth phase for all variations of light, temperature, and nutrition is improbable (26). During very cold weather the species present will most probably be ones more suited to cold

weather and may not be of much quantitative importance during hot weather (4)(66). The amount of light available may limit the quantitative growth of some species (4). The changes induced in ponds by the algae may also cause shifts in the dominant species (48).

As algae grow in ponds the soluble organic content of the ponds tends to decrease, making the ponds more favorable for other species of algae less resistant to high organic concentrations (4). Another factor that the algae bring about will be marked changes in the pH of the ponds. Caldwell (10) reports that the pH of a pond under study varied from 7.4 to 10.2 as the suspended solids (probably mainly algae, since the loading of the pond decreased from 500 to approximately 200 persons per acre) increased from 22 to 121 ppm. Allen (4) believes that when most of the organic matter has been removed and the high pH tends to precipitate mineral nutrients, a mixed flora, including *Chlamydomonas*, succeeds *Chlorella* because the organic compounds excreted by *Chlamydomonas* make the minerals available for algal growth. In general, the most numerous algae will be species of *Chlorella*, *Scenedesmus*, and *Euglena* (4)(65).

Yield

The yield of algae from stabilization ponds will vary with the conditions, as has been already discussed. The amounts of algal material produced can be described by a variety of methods. The average volume of algae settled in Imhoff cones after formaldehyde treatment was 0.13 ml/l for ponds at Shoemaker, Calif. (10)(46). Allen (4) reports the numbers of various species of algae in sewage ponds to be between 5 and 12,540 cells per cubic millimeter. Gotaas and Oswald (25) reported average yields of 30 to 35 tons of dry algae per acre per year from ponds at Richmond, Calif., with rate yields of 60 to 75 tons per acre-year in July and August, and Gotaas *et al.* (27) reported yields of algae of 600 to 1,600 lb per million gallons of sewage. Renn (58) stated that a population of 10,000 persons could produce 1,400 lb of protein per day. Meffert (40) obtained yields of 7 to 10 g per square meter of surface per day during warm weather and 4 g per square meter per day during cool cloudy weather.

In discussing yields of algae grown in sewage or other media, it is important to differentiate between controlled laboratory experiments and field experiments, as well as the culture medium used. Using a small annulus as a growth chamber, a modified Knop solution as medium, and full sunlight, Myers *et al.* (44) were able to obtain *Chlorella* yields of 55 g/l. Yields of 16 g per square meter per day have been reported for cultures in 5-gal. bottles (8). Mayer *et al.* (39) reported that by using a concentrated nutrient medium in outdoor tanks in Israel with a capacity of 2,100 l, *Chlorella* yields of 14 to 21.2 g (dry weight) per square meter of illuminated surface per day were obtained. Thus, the yields obtainable in laboratory or small-scale field experiments may be calculated on the same basis as yields from oxidation ponds, but the magnitude of difference will be considerable.

When analyses of sewage and of algae are compared (see Tables II and III) it becomes apparent that carbon is most apt to be the first nutrient to limit the growth of the algae in oxidation ponds (4)(26)(27)(36)(40)(52). Oswald *et al.* (52) showed that tube cultures of *Chlorella* in sterile sewage required 24.0 mg of carbon per liter per day to maintain a consistent growth rate, whereas the sewage alone contained only 13.2 mg of carbon available per liter per day. The deficit of 10.8 mg of carbon per liter per day was supplied from bubbling air. Also,

it has been calculated that similar cultures of *Euglena* would produce a yield of 1,550 lb of dry algae per million gallons of sewage per day without reaeration; but if carbon is supplied in sufficient amounts to utilize all of the nitrogen in the sewage, a yield of 3,300 lb of dry algae per million gallons of sewage per day would theoretically be possible (26).

Other experiments have indicated that even with air as a source of carbon there is less growth of algae in sewage than when a more concentrated source of carbon dioxide is used (27)(36)(40). Ludwig *et al.* (36) found that the maximum yield of *Euglena* under certain conditions of growth in sewage was 0.080 g/l per day when air was the source of carbon, and with added CO_2 the maximum yield was 0.26 g/l per day. Gotaas *et al.* (27) made a study of the effectiveness of various concentrations of CO_2 for growth of *Euglena gracilis* in tube culture and found that 0.03 per cent CO_2 gave fair growth, 0.5 and 2.0 per cent gave good growth, 4 per cent gave fair growth, and 8 per cent gave poor growth. Naturally, the environmental conditions will determine the most effective method of enriching pond waters with CO_2 for increased algal growth and nutrient utilization. One method that has been found satisfactory in a field application has been the use of sewage gas (30 per cent CO_2) by Meffert in Germany (40). She used 1 to 2 cu m of sewage gas per hour in 1 cu m of pond water (one-fifth of pond volume) as a carbon source and an additional 3 to 4 cu m of air per hour in a cubic meter for optimum turbulence.

Theoretical Yields

From a theoretical point of view, the amount of algal yield to be expected under good growing conditions could be calculated. The nitrogen content of algae grown in sewage may vary from 3 to 5 per cent (26)(40) and the nitrogen content of sewage varies from 20 to 30 ppm. Therefore, if sufficient carbon is available to utilize all of the nitrogen present, algal yields of 400 to 1,000 mg/l of sewage could be expected. Oswald and Gotaas (51) suggest that a rule-of-thumb relationship between sewage nitrogen and growing algae is

$$C_o = 10 \times N,$$

where C_o is the maximum algal cell concentration and N is the nitrogen, both expressed in the same units. In reality, however, the usual report is of maximum yields of algae of 100 to 300 mg/l in oxidation ponds.

Phosphorus Effects

Phosphorus has not been found to be a limiting factor to algal growth in sewage. Laboratory experiments (18) have shown that with 75 per cent of the original 7.3 ppm of soluble phosphorus precipitated by a pH of 9.4 and removed from a sewage plant effluent, *Chlorella pyrenoidosa* grew as fast and as much as in primary settled sewage and in sewage plant effluent that contained 7.3 ppm of phosphorus (approximately 400 mg/l in 14 days). Both magnesium and potassium are also essential to algal growth; but, as in the case of phosphorus, the quantities of each in sewage (usually near 5 ppm), if fully available, are sufficient to support algal concentrations in excess of 500 ppm (51).

Economics of Oxidation Ponds

The relative economics of conventional sewage treatment plants and waste-water oxidation ponds are dependent on local situations. Pond construction requires considerably more available area (10 acres per 1,000 population) (75) than the conventional type of plant. However, the construction costs of primary treatment facilities and, especially, secondary treatment facilities are consider-

ably higher than the initial costs involved in pond construction.

The maintenance requirements are also at a minimum for pond management (10)(20)(21)(34)(37)(61)(69)(75)(76). Thus, it appears that where the area is suitable for pond construction, stabilization ponds can be an effective and economical answer to community disposal problems. The local conditions of an area cannot always be suitable for pond construction, however, even if land is available. Neel and Hopkins (48) and Lackie *et al.* (34) point out problems arising from high percolation rates and possible means of reducing percolation.

The utilization of waste-water ponds beyond the sewage treatment facility stage has been known for several hundred years. In Asia, ponds were constructed and used for fish culture long before their importance as sewage treatment installations was appreciated (42). In 1934 Hoffmann (30) reported that in the Kwangtung province of China, costs for human night soil for fish ponds were $0.54 to $0.62 per 100 lb, as compared to $0.23 for hog manure and $0.05 to $0.06 for cow dung. Reports have indicated that carp thrive especially well in sewage ponds, yields from 500 to 6,000 lb per acre per year being obtained (12)(16)(29)(45)(62)(74)(79). Game fish, such as rainbow trout, black bass, pike-perch, and tench (from the minnow family) have been successfully cultivated in stabilization ponds (11)(12)(62), rainbow trout being raised from fry stage to 250-g fish in one season (62).

Experience in the United States appears to have been mainly limited to using fish for mosquito control. Several species of top minnow (20) and *Gambusia* (minnow fish) (6)(10)(33)(47) have been found to thrive in ponds not overloaded with sewage. One report (56) indicated that a species of *Gambusia* apparently did not survive in a pond that was considered to be overloaded at various times. Gloyna and Hermann (23) point out that 46 per cent of the 188 ponds in Texas in 1957 supported fish life in varying degrees. From the successful experiences in this country and in Europe and Asia, therefore, it appears that economic crops of fish from waste-water ponds are possible. The most promising species will probably be those which can be used for purposes other than direct consumption as food, as there may be both esthetic and hygienic objections to eating a product grown in sewage.

Another possible economic crop of sewage oxidation ponds would be the algae grown in the ponds. Sewage-grown algae do not have as high a protein content as the same species grown in other media (40), but they still can be considered a valuable protein source. However, unlike crops of fish, the harvesting of algae from the dilute suspensions found in oxidation ponds is a very expensive operation and one not completely solved at present (22)(51)(68). In theory, at least, algae could become a very important economic crop. Much work has been done (8) on the use of algae as food or a source of industrial raw materials, and dried sewage-grown algae have been found to have very definite advantages as a food supplement (8)(17); the value of this product as a chicken feed supplement has been calculated to be approximately $100 per ton (51).

Acknowledgment

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References

1.* Anon., "Sewage Lagoon Process." THIS JOURNAL, **26**, 2, 239 (Feb. 1954).

2.* Anon., "The Madison Lakes Problems." Report sponsored by Oscar Mayer & Co., Madison, Wis. (Sept. 15, 1955).

3. Abbott, W. E., "Oxygen Production in Water by Photosynethesis." *Sewage Works Jour.*, **20**, 3, 538 (May 1948).

4. Allen, M. B., "General Feature of Algal Growth in Sewage Oxidation Ponds." Publ. No. 13, California State Water Pollution Control Board (1955).

5.* Birtwistle, W., "Rearing of Carp in Ponds." *Malayan Agr. Jour.* (Aug. 1931).

6. Blackstone, W. W., "Internment Camp Treats Sewage in Ten Lagoons." *Sewage Works Eng. and Munic. Sanit.*, **17**, 14 (1946).

7.* Bose, P. C., "Calcutta Sewage and Fish Culture." *Proc. Natl. Inst. Sci. India*, **10**, 443 (1944).

8. Burlew, J. S. (editor), "Algal Culture from Laboratory to Pilot Plant." Publ. No. 600, Carnegie Inst. of Wash. (1953).

9.* Buschkiel, A. L., "Lehren aus Tropischer Teichwirtschaft." *Zeits. Fischerei* (Germany), **35**, 181 (1937).

10. Caldwell, D. H., "Sewage Oxidation Ponds—Performance, Operation and Design." *Sewage Works Jour.*, **18**, 3, 433 (May 1946).

11. Cronheim, W., "Die Hygienische Bedeutung der Teichwirtschaft." *Arb. Landw. Hochsch.* (Berlin), 253 (1909).

12. Demoll, R., "Die Reinigung von Abwassern in Fischteichen." *Handb. Binnenfischer Mitteleuropas*, **6**, 222 (1926).

13.* Ehlers, V. M., "Oxidation Ponds—Their Application and Potentials." *Off. Bull.*, N. Dak. Water and Sewage Works Conf. (Sept. 14, 1954).

14. Ellison, R. J., and Smith, R. L., "Evaluating the Use of Sewage Lagoons." *Pub. Works*, **85**, 89, 142 (Mar. 1954).

15.* Espinosa, A. J., "The Role of Algae in Waste Treatment." *Pub. Works*, **79**, 36 (Aug. 1948).

16. Falck, T., "The Development of Sewage Treatment in Fish Ponds." *abs. Sewage Works Jour.*, **8**, 1, 150 (1936).

17. Fink, H., "On the Protein Quality and the Liver Necrosis Preventive Factor of Unicellular Algae." Solar Energy Conf., Tucson, Ariz. (Aug. 31, 1955).

18. Fitzgerald, G. P., Unpublished experiments on Growth of Algae in Sewage and Sewage Plant Effluent. San. Eng. Lab., Univ. of Wis. (Feb. 1956).

19. Gerloff, G. C., and Skoog, F., "Cell Contents of Nitrogen and Phosphorus as a Measure of Their Availability for Growth of *Microcystis aeruginosa*." *Ecology*, **35**, 348 (1954).

20. Giesicke, F. E., and Zeller, P. J. A., "Secondary Treatment of Sewage in an Artificial Lake." *Eng. News-Rec.*, **117**, 674 (1936).

21. Gillespie, C. G., "Emergency Land Disposal of Sewage—Discussion." *Sewage Works Jour.*, **16**, 4, 740 (July 1944).

22. Gloyna, E. F., Hermann, E. R., and Drynan, W. R., "Oxidation Ponds." Tech. Rep. No. 2, San. Eng. Lab., Univ. of Texas (June 1, 1955).

23. Gloyna, E. F., and Hermann, E. R., "Algae in Waste Treatment—Discussion." THIS JOURNAL, **29**, 4, 455 (Apr. 1957).

24.* Gotaas, H. B., and Oswald, W. J., "Algal-Bacterial Symbiosis in Sewage Oxidation Ponds—Third Progress Report." Bull. Series 44, No. 4, pp. 1–45, Inst. of Eng. Research, Univ. of California (1952).

25. Gotaas, H. B., and Oswald, W. J., "Utilization of Solar Energy for Waste Reclamation." Solar Energy Conf., Tucson, Ariz. (Aug. 31, 1955).

26. Gotaas, H. B., Oswald, W. J., *et al.*, "Algal Symbiosis in Oxidation Ponds —Second Progress Report." Bull. Series 44, No. 3, pp. 1–58, Inst. of Eng. Research, Univ. of California (1951).

27. Gotaas, H. B., Oswald, W. J., and Golueke, C. G., "Algal-Bacterial Symbiosis in Sewage Oxidation Ponds—Fifth Progress Report." Bull. Series 44, No. 5, pp. 1–88, Inst. of Eng. Research, Univ. of California (1954).

28.* Hall, G. L., "Dense Algal Growths in Stream Stimulated by Sewage Effluents." *Sewage Works Eng. and Munic. Sanit.*, **18**, 94 (1946).

29. Hickling, C. F., Unpublished notes made on a tour of the far east in 1947, quoted in "Fertilizers in Fishponds," C. H. Mortimer, Colonial Off., London, Fish. Publ. No. 5 (1954).

30. Hoffmann, W. E., "Preliminary Notes on the Freshwater Fish Industry of South China, Especially Kwangtung Province." Lingnan Univ. Sci. Bull. No. 5, Canton (1934).

* These references not quoted in text but provide additional sources of related information.

31.* Kamman and Keim, "Über Abwasserreinigung in Gewässern Insbesondere im Versuchsteich auf der Klaranlage in Bergedorf bei Hamburg." *Gesundh.-Ing.* (Germany), **43**, 229 (1920).

32. Kisskalt, K., and Ilzhofer, H., "Die Reinigung von Abwasser in Fischteichen." *Arch. Hyg. u. Bact.* (Berlin), **113** (1937).

33. Knowlton, W. T., "Emergency Land Disposal of Sewage—Discussion." *Sewage Works Jour.*, **16**, 4, 744 (July 1944).

34. Lackie, T. H., Prescott, M. H., and Hogge, H. L., "Experiences with Sewage Lagoons in the Prairie Provinces." *Munic. Util. Mag.*, **95**, 24 (1957).

35.* Ludwig, H. F., and Oswald, W. J., "Role of Algae in Sewage Oxidation Ponds." *Sci. Monthly*, **74**, 1 (1952).

36. Ludwig, H. F., Oswald, W. J., Gotaas, H. B., and Lynch, V., "Algae Symbiosis in Oxidation Ponds. I. Growth Characteristics of *Euglena gracilis* Cultured in Sewage." THIS JOURNAL, **23**, 11, 1337 (Nov. 1951).

37. Malchow-Moeller, O., Bonde, G. J., and Fjerdingstad, E., "Treatment of Domestic Sewage in Lagoons." *Schweiz. Z. Hydrol.* (Switzerland), **17**, 98 (1955).

38.* Mayenne, V. A., "Abwasserreinigung durch Mehrstufig Teiche und Fischzucht in Denselben." *Arch. Hydrobiol.*, **25**, 648 (1933).

39. Mayer, A. M., Eisenberg, A., and Evanari, M., "Studies on the Deep Mass Culture of Algae in Israel." Solar Energy Conf., Tucson, Ariz. (Aug. 31, 1955).

40. Meffert, M. E., "Algal Culture in Sewage." Solar Energy Conf., Tucson, Ariz. (Aug. 31, 1955).

41. Merz, R. C., Merrell, J. C., and Stone, R., "Investigation of Primary Lagoon Treatment at Mojave, California." THIS JOURNAL, **29**, 2, 115 (Feb. 1957).

42. Mortimer, C. H., "Fertilizers in Fish Ponds." Colonial Office, London, Fish. Publ. No. 5 (1954).

43. Myers, J., "Studies of Sewage Lagoons." *Pub. Works*, **79**, 25 (Dec. 1948).

44. Myers, J., Phillips, J. N., and Graham, J., "On the Mass Culture of Algae." *Plant Physiol.*, **26**, 539 (1951).

45. Nair, K. K., "Calcutta Sewage Irrigation Fisheries." *Proc. Natl. Inst. Sci. India*, **10**, 459 (1944).

46. Natl. Research Council, "Sewage Treatment at Military Installations. Chapt. IX, Oxidation Ponds." *Sewage Works Jour.*, **18**, 5, 1023 (Sept. 1946).

47. Natl. Research Council, "Sewage Treatment at Military Installations—Summary and Conclusions." *Sewage Works Jour.*, **20**, 1, 52 (Jan. 1948).

48. Neel, J. K., and Hopkins, G. H., "Experimental Lagooning of Raw Sewage." THIS JOURNAL, **28**, 11, 1326 (Nov. 1956).

49.* O'Connell, W. L., Jr., and Gray, H. F., "Emergency Land Disposal of Sewage." *Sewage Works Jour.*, **16**, 4, 729 (July 1944).

50.* Oesten, G., "Nutzfarmachung der Kanalisations—und Ahnlichen Abwassern Enhaltenen Stoffe zur Fischzucht." abs. *Z. Angew. Chem.*, **22**, 531 (1899).

51. Oswald, W. J., and Gotaas, H. B., "Photosynthesis in Sewage Treatment." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **81**, 686 (May 1955).

52. Oswald, W. J., Gotaas, H. B., Ludwig, H. F., and Lynch, V., "Algae Symbiosis in Oxidation Ponds. II. Growth Characteristics of *Chlorella pyrenoidosa* Cultured in Sewage." THIS JOURNAL, **25**, 1, 26 (Jan. 1953).

53. Oswald, W. J., Gotaas, H. B., Ludwig, H. F., and Lynch, V., "Algae Symbiosis in Oxidation Ponds. III. Photosynthetic Oxygenation." THIS JOURNAL, **25**, 6, 692 (June 1953).

54. Oswald, W. J., Gotaas, H. B., Golueke, C. G., and Kellen, W. R., "Algae in Waste Treatment." THIS JOURNAL, **29**, 4, 437 (Apr. 1957).

55. Parker, C. D., Jones, H. L., and Taylor, W. S., "Purification of Sewage in Lagoons." THIS JOURNAL, **22**, 6, 760 (June 1950).

56. Pearse, L., *et al.*, "Oxidation Ponds." Report by Committee on Sewage Disposal, Engineering Section, American Public Health Association, *Sewage Works Jour.*, **20**, 6, 1025 (Nov. 1948).

57.* Pillai, S. C., *et al.*, "Protozoal Development and Natural Purification of Flowing Sewage." Abs. THIS JOURNAL, **26**, 8, 1055 (Aug. 1954).

58. Renn, C. E., "Algae Research on Oxidation Ponds." *Amer. Jour. Pub. Health*, **44**, 631 (1954).

59. Sampson, E. O., "A Double Duty Oxidation Pond." THIS JOURNAL, **27**, 12, 1410 (Dec. 1955).

60.* Schaeffer, J. G., "Sewage Treatment and Disposal by Lagooning." *Munic. Util.*, **92**, 11, 49 (1954).

* These references not quoted in text but provide additional sources of related information.

61. Schaeffer, J. G., "The Treatment of Sewage by Lagooning." *Canad. Jour. Pub. Health*, **48**, 438 (1957).

62. Scheuring, D. L., "Die Reinigung und Verwertung der Abwasser von Munchen." *Natur u. Volk* (Germany), **69**, 390 (1939).

63.* Schillinger, A., "Die Biologische Reinigung Stadtischer Abwasser in Abwasserfischteichen." *Vom Wasser* (Germany), **2**, 200 (1928).

64.* Schillinger, A., "Über die Abwasserreinigung in Fischteichen." *Gesundh. Ing.* (Germany), **58**, 192 (1935).

65. Silva, P. C., and Papenfuss, G. F., "A Systematic Study of the Algae of Sewage Oxidation Ponds." Publ. No. 7, State Water Poll. Control Bd., Sacramento, Calif. (1953).

66. Smallhorst, D. F., Walton, B. N., and Myers, J., "Design and Application of Oxidation Ponds." *Pub. Works*, **84**, 12, 89 (1953).

67. Steele, E. W., and Gloyna, E. F., "Concentration of Radioactivity in Oxidation Ponds." THIS JOURNAL, **27**, 8, 941 (Aug. 1955).

68. Steele, E. W., and Gloyna, E. F., "Oxidation Ponds—Radioactivity Uptake and Algae Concentration." *Pub. Health Eng. Abs.*, **34**, 9, 16 (1954).

69. Stene, S., "Lagoon System with Artificial Aeration and High Recirculation." Private communication, Oslo, Norway (1955).

70.* Stone, A. R., and Abbott, W. E., "Microscopic Green Organisms as Agents of Sewage Purification." abs. THIS JOURNAL, **22**, 10, 1378 (Oct. 1950).

71. Towne, W. W., Bartsch, A. F., and Davis, W. H., "Raw Sewage Stabilization Ponds in the Dakotas." THIS JOURNAL, **29**, 4, 377 (Apr. 1957).

72.* Towne, W. W., Bartsch, A. F., Davis, W. H., and Graves, Q. B., "Waste Stabilization Ponds." Robert A. Taft San. Eng. Center, U. S. Public Health Service, Cincinnati, Ohio (1956).

73.* Tsivoglou, E. C., Pecsok, D. A., and Valentine, R. F., "Field Use of Radiotracer in a Sewage Oxidation Pond Flow Study." THIS JOURNAL, **28**, 10, 1211 (Oct. 1956).

74. Vaas, K. F., "Notes on Freshwater Fish Culture in Domestic Sewage in the Tropics." *Landbouw* (Indonesia), 20 (1948).

75. Van Heuvelen, W., and Svore, J. H., "Sewage Lagoons in North Dakota." THIS JOURNAL, **26**, 6, 771 (June 1954).

76. Wennström, M., "Oxidation Ponds in Sweden." *Lunds Univ. Arsprift. N.F. Avd. Z. Bd.* 51, No. 7 (1955).

77.* Wennström, M., "Biological Purification of Settled Sewage in Shallow Ponds —Lund, Sweden." *Off. Bull.*, N. Dak. Water and Sew. Conf., p. 9 (Sept. 1954).

78.* Wilson, J. N., "How Sanitary Biologists Contribute to Water Treatment Processes." *Water and Sewage Works*, **100**, 502 (1953).

79. Wundsch, H. H., "Die Reinhaltung Unserer Fischgewasser." *Handb. Binnenfisch Mitteleurop.*, **6**, 138 (1926).

* These references not quoted in text but provide additional sources of related information.

FUTURE SANITARY ENGINEERS

The Federation has on hand a supply of *Toward a Healthier World: Your Career in Sanitary Engineering.* These are available to anyone forwarding a request to the Federation office.

Announcement was previously made (THIS JOURNAL, **30**, 2, 137; Feb. 1958) of this booklet and its availability from the Public Health Service.

This 16-page publication is aimed at the secondary school student to serve as a guide for his consideration of sanitary engineering as a career. In it the role of the sanitary engineer, his future needs, varied opportunities, courses required, availability of fellowships and traineeships, and salaries are outlined in a straightforward, interesting way.

The Federation recommends this as a valuable aid in the encouragement of young students to select sanitary engineering as a career.

TEMPERATURE EFFECTS ON ANAEROBIC DIGESTION OF RAW SEWAGE SLUDGE

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Temperature has long been recognized as one of the more important factors controlling the rate and course of digestion of sewage sludge. Until quite recently it was generally assumed that limited bacterial activity occurs in the temperature zone dividing the upper level of the mesophilic range and the lower level of the thermophilic range, resulting in a plateau in any curve representing the relationship between temperature and any normal rate of digestion (1)(2). According to this assumption the optimum temperature for mesophilic digestion generally was assumed as between 30 and 40°C, and that for thermophilic digestion, between 50 and 60°C. Within the temperature range of 40 to 50°C, neither mesophilic nor thermophilic organisms supposedly would flourish, and digestion, therefore, would be slow and unsatisfactory. The concept is now being questioned as a result of work done in fundamental bacteriology (3) and in large scale operations (4).

Reported studies of the effect of temperature on the sludge digestion process have generally been limited to a relatively few temperature levels, mostly confined to only one of the thermal zones, either the mesophilic (30 to 40°C) or the thermophilic (50 to 65°C). Moreover, only a few parameters by which digester performance can be judged were related to temperature in any single study. The investigation herein was, therefore, set up to investigate simultaneously and under controlled conditions the relationship of temperature throughout the entire range of 30 to 65°C on a wide variety of parameters, for judging digester performance.

Materials and Methods

Eight 19-l pyrex bottles were used as digesters. Four of these were placed in water baths in which the temperature was maintained at 30°C, 35°C, 40°C, and 45°C, ± 1°C, respectively. The other four were placed in specially constructed insulated thermal cabinets in which temperatures were maintained at 50°C, 55°C, 60°C, and 65°C, respectively. All digesters were operated simultaneously to rule out effects of changes in raw sludge quality. The four lower temperature digesters were charged with 14 l of digesting sewage sludge obtained from digesters operated by the local sanitary treatment district. The remaining digesters received 10.5 l of digesting sludge plus 3.5 l of raw sludge. These were allowed to remain undisturbed until a suitable bacterial population had been built up, at which time a regular feeding program was begun. A gas production of 6 l per day was arbitrarily assumed to indicate the establishment of a suitable population. As is shown in Figure 1, the digesters were equipped with devices for collecting gas and pumps for injecting feed, and circulating and withdrawing digesting sludge.

Operation

All digesters were fed raw, settled sewage sludge once a day and an equal quantity of digesting sludge (mixed liquor) was withdrawn directly before

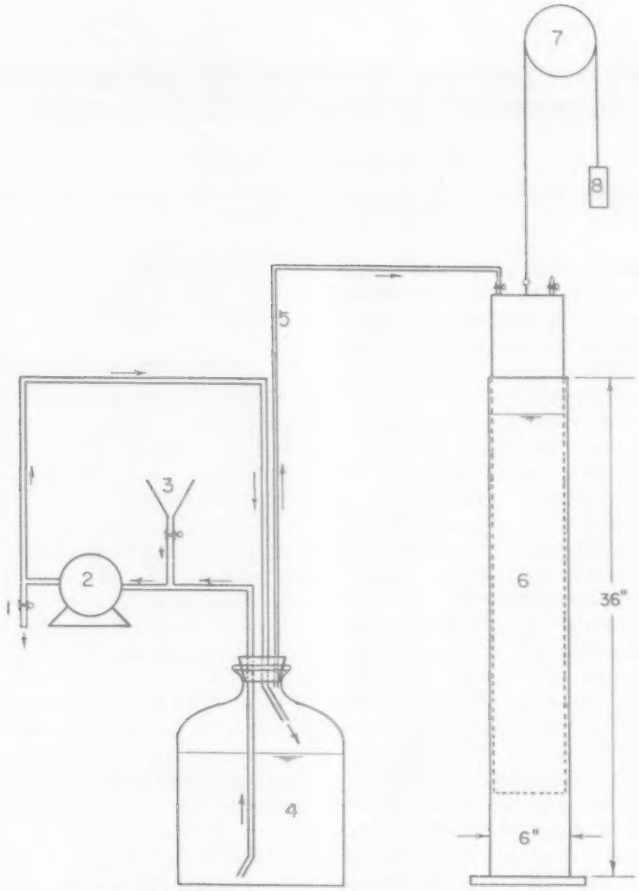

FIGURE 1.—Schematic drawing of a complete digester unit, including inlet port for feeding, outlet port for sampling, and gas plenum for collecting gas. The plenum consists of two tubes of lucite, one telescoping into the other. A solution of HCl (1 per cent) acts as a seal to prevent the escape of gas.

feeding. The amount of nutrient added each day furnished 41 g (0.09 lb) of volatile matter per 28.3 l (1 cu ft) of digesting culture. By adding 467 ml of raw sludge and removing an equal amount, it was possible to establish a detention period of 30 days. Uniform and homogeneous samples were obtained by manually shaking the digesters thoroughly and allowing the pumps to recycle the sludge for 5 min before removing the sample. Samples

were analyzed to determine total solids, volatile matter, volatile acid content, alkalinity, and pH.

Solids and alkalinity were determined by procedures described in "Standard Methods" (4). Volatile acids were extracted by a modified liquid-liquid ether extraction method and are expressed as acetic acid in mg/l of sludge. Total volume of gas produced was determined prior to feeding. Composition of the gas was determined by means of a Fisher gas analyzer. CO_2, O_2, and CH_4 were determined directly; H_2 and N_2 values were arrived at by calculation.

Mass Balance

A mass balance was made for each digester so that a record of volatile matter destruction, total gas production, and constituent gases could be obtained. In making the mass balance, an attempt was made to account for the volatile matter introduced as feed in terms of volatile matter remaining undecomposed after digestion, and that converted to gas. To obtain such a balance, it was necessary to determine the loss in volatile matter resulting from the digestion process and to account for the decomposed material in terms of gas produced. Mass balances were made after the digesters had reached a state of equilibrium, i.e., were destroying volatile matter and producing gas at a relatively uniform rate. Each fourth day the values for volatile matter destruction and gas production for each of the intervening days were averaged and a mass balance made for the four-day interval. Seven to ten such mass balances were made for each experiment, depending on the duration of the experiment.

Sludge Characteristics

Observations on sludge characteristics took into consideration odor, color, and the facility with which it could be dewatered. The dewatering characteristics of the various sludges were determined as follows: an aliquot of digested sludge was treated with 12 per cent $Ca(OH)_2$ and varying concentrations of $FeCl_3$ and then placed in a Buchner funnel. A negative pressure equivalent to 10 in. of Hg was applied. Relative ease of dewatering was determined by correlating the length of time required for a crack to develop in the filter cake and concentration of $FeCl_3$.

No attempt was made to isolate and identify the organisms active in the cultures. Occasional microscopic observations were made on the sludge to determine the gross morphology of the organisms involved and their relative number.

Results

Digesters operating at 30 to 40°C inclusive began to function as soon as they were set up. A period of 7 days was required for the 45°C digester and approximately 21 days for the higher temperature digesters.

As shown in the summary of mass balances listed in Table I and in Figure 2, extent of destruction of volatile matter averaged 40 per cent at 30°C, 50 to 53 per cent at temperatures 35 to 55°C, inclusively, and 47 per cent at 60°C. No mass balance was made for the 65°C digester because gas production and spot checks showed destruction of volatile matter to be almost negligible.

Gas Production

When a population was well-established in a particular digester, it became very sensitive to any abrupt drop in temperature, which occasionally happened because of temporary failure of equipment. Thus, a drop of 5°C, lasting 16 to 18 hr, in the 60°C digester resulted in a decline in destruction of volatile matter from 47.4 per cent to 38.8 per cent for the 4-day period; a drop of 5°C (16 to 18 hr) reduced the breakdown from 49.9 per cent to 38 per cent for the 55°C di-

TABLE I.—Summary of Mass Balances for Digesters Fed 20.8 g Volatile Matter Per Day (0.09 lb/cu ft of Culture)*

Temp (°C)	Avg Destruction of Vol. Matter Introduced (%)	Avg Gas Produced (g)						Gas Produced
		CO_2	O_2†	CH_4	H_2	N_2 and Other Gases‡	Total	Vol. Matter Destroyed (Avg)
30	40.7	19.1	0.96	15.5	0.09	2.52	38.20	1.25
35	52.8	20.8	0.64	16.3	0.02	2.45	40.21	1.12
40	51.8	25.8	0.51	18.0	0.01	2.55	47.87	1.15
45	52.4	25.2	0.39	16.7	0.03	2.19	44.51	1.15
50	51.1	27.2	0.91	20.6	0.09	4.16	52.96	1.29
55	49.9	25.2	0.36	18.6	1.00	2.69	47.85	1.18
60	47.4	24.6	0.89	18.1	0.01	2.34	45.94	1.22

* Culture volume, 14 l.
† O_2 "Production" in reality represents leakage of external air into the digester
‡ Weight estimated as nitrogen and other gases.

gester; and a 10°C (16 to 18 hr) drop resulted in a reduction in breakdown for the 35°C digester from 52.8 per cent to 44 per cent.

As is shown in Figure 3, gas production varied from 8.8 l per day at 30°C to a high of 11.3 l per day at 50°C, and very little if any production at 65°C. Gravimetric values for total gas production as well as individual components of the total are given in Table I. Variations in the percentages of the total gas produced measured volumetrically were as follows: CO_2, from 27.9 per cent in the 30°C digester to 32.3 per cent in the 45°C digester, and CH_4, from 57.8 per cent in the 45°C digester to 60.8 per cent in the 55°C digester. Thus, the volumetric ratio of CO_2 to CH_4 varied from 1.78 (45°C digester) to 2.16 (30°C). Gravimetrically, the

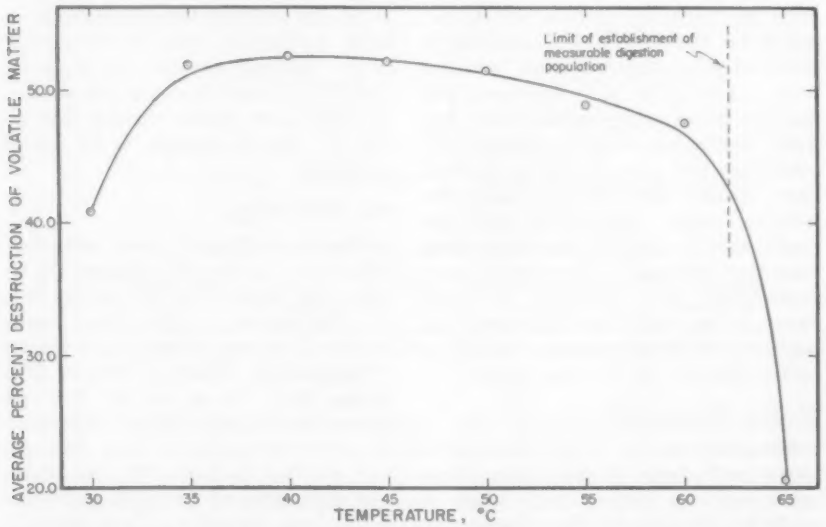

FIGURE 2.—Average per cent destruction of volatile matter as a function of the temperature at which a digester operated.

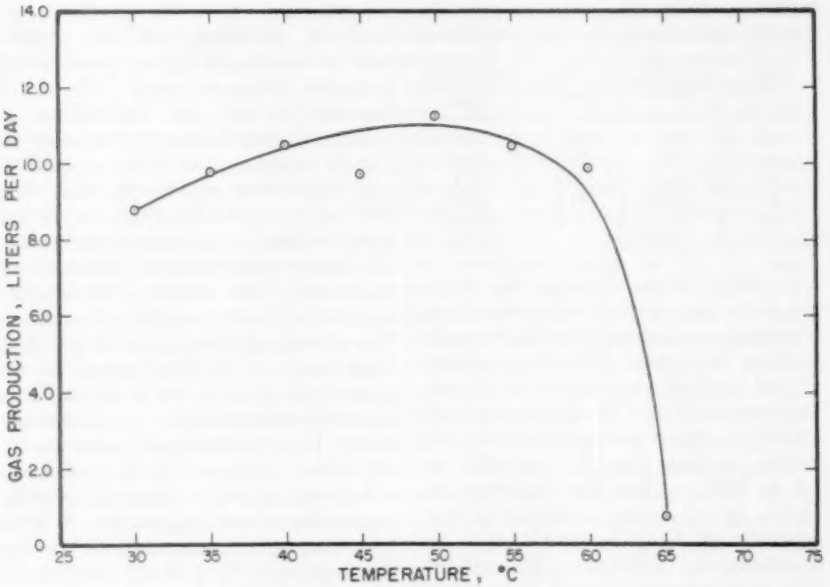

FIGURE 3.—Average daily gas production.

ratio varied from 1.27 (30°C) to 1.38 (55°C).

Volatile Acids

Total volatile acid content increased with increase in temperature. Thus, as shown in Figure 4, the 35°C digester contained only 82 mg/l (expressed as acetic acid) compared to 2,210 mg/l at 65°C. A chromatographic analysis of the acids produced showed them to consist of acetic, butyric, propionic,

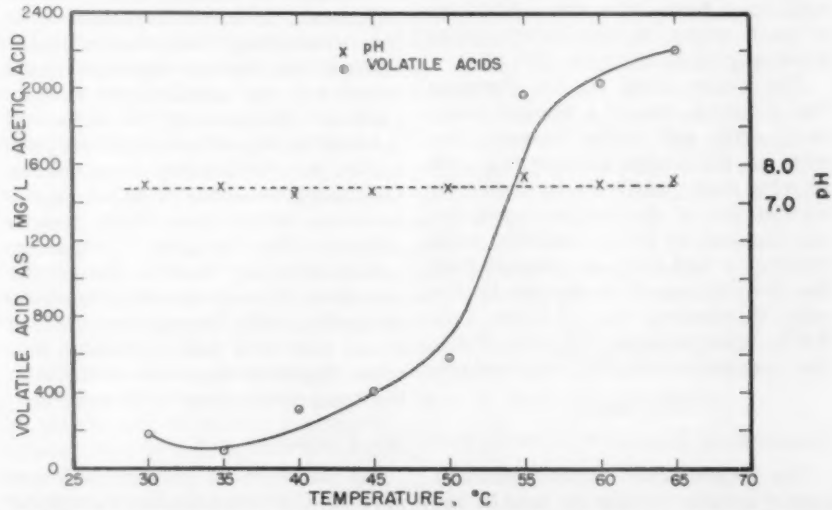

FIGURE 4.—The effect of temperature on pH and volatile acid content of the digesters.

TABLE II.—Sludge Dewatering Characteristics

Temp (°C)	$Ca(OH)_2$ (% of Dry Solids)	$FeCl_3$ (% of Dry Solids)	Time for Sludge Cake to Crack (Min)
35	12	24	3.90
40	12	24	3.33
45	11.5	38.8	3.71
50	11.9	11.9	3.35
60	11.0	17.9	3.90

and valeric acids. Because R_f values for acetic and formic acids are almost identical, no distinction could be made between these two. This same pattern of acid production persisted at all temperatures studied. Hydrogen-ion concentration variation was not great, pH values varying from 7.2 at 40°C to 7.6 at 65°C. Alkalinity expressed as $CaCO_3$ in mg/l (an indication of the quantity of basic materials such as bicarbonates, carbonates, hydroxides, and other alkalies) varied from 4,040 at 45°C to a high of 5,583 at 55°C.

Other Observations

At all temperatures, the predominant flora consisted of short rods (0.3 to 3 microns) with long rods (3 to 6 microns) next in number; an occasional spirillum form was observed, and coccal forms were rare. Numbers of each group in the order named were roughly in the ratio 100 : 50 : 1.

The sludge from all the digesters was similar in having a blackish color, tarry odor, and gritty texture. Results of the sludge conditioning and filtering tests, as listed in Table II, showed that of the sludges tested, the one digested at 50°C dewatered most readily, in that for a comparable time for the first crack to appear in the cake, it required only 11.9 per cent $FeCl_3$, whereas 38.8 per cent $FeCl_3$ was required at the 45°C temperature.

Discussion

Temperature Ranges

The experiments demonstrate that once a suitable population is built up, digestion proceeds equally well at all temperatures from 35 to 60°C, inclusively, provided that the population is maintained at the temperature to which it was adjusted. The sharp increase in per cent destruction of volatile matter occurring between digesters operating at 30°C and 35°C may have been due to the fact that 35°C is the optimum temperature for most members of the mesophilic group. At higher temperatures, selection of populations best suited to the operating temperature probably takes place. The absence of any decline in per cent destruction of volatile matter in digesters operating at 40°C and 45°C is especially interesting. As previously stated, these temperatures have generally been considered to be inhibitory to bacterial activity, inasmuch as these temperatures were supposed to be high for mesophilic organisms and low for thermophiles. If a sharp line of demarcation did exist in the temperature tolerances of mesophilic and thermophilic organisms, such a zone would be plausible; but the difficulty of workers in establishing absolute values for the upper mesophilic and the lower thermophilic zones indicates an overlapping of the two (3)(5). Inasmuch as digestion is carried on by a mixed population, it is not improbable that the overlapping temperature tolerances of the various organisms would cancel out any so-called temperature plateau. Moreover, if the organisms involved in digestion at high temperatures are facultative thermophiles, they could be active at any temperature to which they had become adapted. The findings in these experiments reflect those of Garber (6) who found no such transition zone. As far back as 1933, Heukelekian (7) had found that with batch processes ultimate digestion time varied little in the temperature range of 29 to 42°C.

Gas Production

The variation in average daily gas production between digesters operating at temperatures of 35 to 60°C was not

significant; nor was there any great variation in the composition of the gases produced, although the ratio of CH_4 to CO_2 was somewhat low at 45°C. The fact that gas production was fairly uniform at all of the temperatures tested indicates either that the methane producers involved were facultative thermophiles or that a group of mesophiles prevailed at the lower temperatures and thermophiles at the higher temperatures. The absence of a transition zone would seem to indicate facultative thermophiles.

In Table II, the O_2 represents leakage of air from the external environment, and hence should be disregarded when judging gas production. Variations in H_2 and N_2 production as listed in the table should not be regarded as having a high degree of significance because they were not determined directly, but were calculated by difference. Hence, any extreme variation probably is only apparent and may be the result of experimental error.

Volatile Acids

Volatile acid content was low at the lower temperatures and increased rapidly with increase in temperature, so that acid content at 50°C was approximately 7 times that at 35°C; and at 60°C, approximately 25 times as great. This would indicate, either that the organisms responsible for decomposition of acid were not functioning efficiently at the higher temperatures, resulting in an accumulation of acid; or, less probably, acid-formers functioned more efficiently or were more numerous and, thus, acid accumulated. Probably, the former was true since the total acid content at 65°C, at which very little activity took place, differed but slightly from that at 60°C.

Whichever of the possibilities may have been true, this phase of population activity did differ with increase in temperature. The difference in population perhaps was one of number and efficiency rather than of species because the chromatograms showed great similarity in type of acid produced, indicating comparable pathways of destruction. If methane organisms were solely responsible for acid decomposition, the high acid content would indicate less activity at the high temperatures. However, gas production remained unchanged, hence their activity apparently was not affected. If the specificity of methane producers had restricted them to one or two groups, acid would have accumulated, but would have been limited to one or two types. Since the ratio of types of acids remained unchanged it is evident that this did not happen. Volatile acid content had little effect on the pH of the digesters because of the high alkalinity, an indication that the carbonate buffering capacity did effectively neutralize any increase in acid that may have occurred. As a result, pH was higher in the 45 to 64°C digesters than at 35°C, in which the acid content was only 82 ppm.

Bacterial Population

Gross observations made on the morphology of the bacteria found in samples of sludge digested at the various temperatures showed little difference in the type of bacteria. These observations differ somewhat from those made by Garber (6) in his studies at Los Angeles. Garber noted a predominance of coccal-type organisms at the lower temperatures and rod shapes at 50°C. The difference in bacterial population observed by Garber and that observed here is not surprising, considering the versatile nature of raw sludge, the material used as feed in both studies. In this investigation, the similarity of gas composition, nature of volatile acid breakdown, and general behavior of digesters, all indicate a similarity in type of bacterial population.

Other Observations

If amount of chemical dosage is considered, together with time required to dewater the sludge according to a uni-

form standard, sludge digested at 50°C and 60°C would seem to have the best dewatering characteristics. This agrees with the observations made by Garber.

Other characteristics of the 50°C and 60°C sludges, such as granularity, odor, and rapidity of separating into solid and liquid phases, indicated their superiority. Fischer and Greene (8) had a different experience, in that they found that sludge digested at high temperatures had poor overflow liquor and was difficult to dewater, although these disadvantages were entirely overcome by multistage digestion. Their difficulty could have been due to inadequately adapted digesters and, hence, poor digestion. The correlation between the superior filterability of sludge obtained at 50°C and general morphology of the predominant organisms as noted by Garber, could not be detected in the present study.

The similarity in extent of destruction of volatile matter, composition of gas, volatile acid products formed, and general performance of the digesters point to a similarity of type of bacterial population at all temperatures tested. The results also indicate the absence of the so-called "plateau-zone" in digesters, once a population has been established, because over-all performance at 40 to 45°C was on a par with that of the other digesters.

Summary

A study was made of the efficiency of the performance of digesters operating at 30°C, 35°C, 40°C, 45°C, 50°C, 55°C, 60°C, and 65°C. Efficiency of digesters was judged on the basis of the destruction of volatile matter introduced into the digesters, gas production, and physical characteristics of the digested sludge.

With digesters operating at 35 to 60°C, inclusively, the per cent destruction of volatile matter, volume of gas production, and ease of dewatering of the digested sludge surpassed that of the 30°C digester. Within the temperature range of 35 to 60°C, inclusively, no significant difference in results could be noted, although the sludges obtained from the 50°C and 60°C digesters were somewhat superior to those from the remaining digesters. Very little, if any, activity took place in the one operating at 65°C.

Composition of gas, nature of the volatile acids formed, and general morphology of the bacterial populations were similar in all of the digesters. The average volatile acid content of the digesters increased with increase in temperature, from a low of 82 ppm at 35°C to a high of 2,210 ppm at 65°C. Similarly, the average pH of the cultures increased from pH 7.3 at 35°C to 7.6 at 65°C.

References

1. Fair, G. M., and Moore, E. W., "Time and Rate of Sludge Digestion, and Their Variation with Temperature." *Sewage Works Jour.*, **6**, 1, 3 (Jan. 1934).
2. Symons, G. E., "Sludge Digestion Tank Heating and Related Problems—A Panel Discussion." THIS JOURNAL, **22**, 1, 104 (Jan. 1950).
3. Allen, M. B., "The Thermophilic Aerobic Sporeforming Bacteria." *Bact. Reviews*, **17**, 125 (1953).
4. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).
5. Campbell, L. L., "The Growth of an 'Obligate' Thermophilic Bacterium at 36°C." *Jour. Bact.*, **68**, 505 (1954).
6. Garber, W. F., "Plant-Scale Studies of Thermophilic Digestion at Los Angeles." THIS JOURNAL, **26**, 10, 1202 (Oct. 1954).
7. Heukelekian, H., "Digestion of Solids Between the Thermophilic and Non-Thermophilic Range." *Sewage Works Jour.*, **5**, 5, 757 (Sept. 1933).
8. Fischer, A. J., and Greene, R. A., "Plant Scale Tests on Thermophilic Digestion." *Sewage Works Jour.*, **17**, 4, 718 (July 1945).

STATE PRACTICES IN SEWAGE DISINFECTION

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The year 1957 marked the 50th anniversary of the first effective domestic application of sewage chlorination on a plant scale at Red Bank, N. J. It also marked the 70th anniversary of the first United States patent for a process covering the use of chlorine for sewage deodorization and disinfection (The Powers process, which utilized chlorine gas evolved from the reaction of manganese dioxide, salt, and sulfuric acid, and the Woolf process (1893), which utilized electrolytic sodium hypochlorite, were used experimentally in New York and elsewhere, but fell into disuse prior to 1910.)

Application of chloride of lime for disinfection of infectious body wastes prior to sewer discharge in England was described in 1879. No scientific studies of the bactericidal action of chlorine are known to have been made, however, until 1894. From then until 1907 the action of chlorinated lime was investigated extensively there, as well as in France and Germany, where the success of limited applications was demonstrated. Thereafter many bacteriological investigations were also undertaken in the United States.

The adoption of chlorination for sewage disinfection and odor control progressed slowly in the United States, primarily because of the expense and difficulties in handling chloride of lime, which was the best source of chlorine commercially available. Impetus to its application and development came with the commercial availability of compressed chlorine gas in 1909, and of proprietary chlorinators in 1912–13. Table I illustrates how the practice has grown.

Use of chlorine in sanitary and industrial waste treatment processes for purposes other than disinfection and odor control developed only many years later (6). Although the use of chlorine for disinfection constitutes its most important application, as an adjunct to primary and secondary sewage treatment the benefits are manifold. This report, however, deals only with its use for disinfection.

Regulatory Bodies

Federal

The first Federal Water Pollution Control Act was enacted in 1948 by the 80th Congress; in July 1956 it was strengthened and became Public Law 660 of the 84th Congress. The law provides generally for state and regional authority for enforcement of water pollution abatement, but it also contains provision for federal intervention where state or regional action is lacking and interstate streams are involved.

The federal government has no official position relative to disinfection of municipal or other wastes discharged into surface and other water systems. Moreover, it has neither established any stream classification schemes nor has it promulgated any qualitative standards for surface waters or spent waters discharged thereto.

Regional

Where interstate waters are involved, some states have organized cooperative agencies, or compacts, such as the Interstate Commission on the Potomac River Basin, the New England Interstate Water Pollution Control Com-

TABLE I.—Development of Use of Chlorine in Sewage Treatment in the United States (1910–1948)

Year	Ref.	Number of Plants			Est. Pop. Served $\times 10^6$		Per Cent of Served Population Wastes Chlorinated	Est. U.S. Population $\times 10^6$	Per Cent of Total U.S. Population Wastes Chlorinated
		Total	Using Chlorine	Per Cent Using Chlorine	All Plants	Plants Using Chlorine			
1910	1	619	22[1]	3.6	4.455	0.109	2.4	92.0	0.12
1916	1	846	55[2]	6.5	6.145	0.282	4.6	99.0	0.28
1934	2	3,697	655	17.7	22.200	—	—	123.077	—
1940	3	5,580	1,127	20.2	40.618	14.336	35.3	131.958	10.9
1945	4	5,786	1,262	21.8	46.865	16.029	34.2	132.481	12.1
1948	5	6,058	1,307	21.6	48.698	18.037	37.0	146.093	12.3

[1] Includes 6 plants serving 64,533 where disinfection alone was practiced, all in New Jersey.
[2] Includes 3 plants serving 25,814 where disinfection alone was practiced, 2 in New Jersey and 1 in North Carolina.

pact, the three-state Interstate Sanitation Commission, and the eight-state Ohio River Valley Sanitation Compact (ORSANCO). Such groups, usually without enforcement powers (with the exception of ORSANCO and the Interstate Sanitation Commission), define standards of water quality, often through stream classification, or establish recommended or required limits of pollutional discharges. For example, ORSANCO provides that wastes discharged into the Ohio River be treated to effect an 85 per cent reduction in coliforms during May through October, and a 65 per cent reduction during the balance of the year; accordingly, municipalities in signatory states along the Ohio River usually provide disinfection to effect such reductions.

State

Most states have enacted rather complex water pollution control legislation. State health departments traditionally were the first water pollution control agencies stemming from the basic health and esthetic considerations associated with dual use of surface waters as public water supplies and as depositories for public wastes. As a result of increased industrialization and the more complex and diversified uses of water in the post-war technology, water pollution has come to be regarded more as a matter of economy and conservation than as a basic health problem in some places. As a result, an increasing number of states have created separate water pollution control agencies that have complete jurisdiction over the waters of the state. More than half the states currently have water pollution control commissions that function independently or share responsibility with state health authorities. In such states, the degree to which public health and conservation agencies are associated and coordinated varies considerably.

Disinfection Requirements

Ten State Standards

The "Ten State Standards" (7) of the Upper Mississippi River and Great Lakes Drainage Basins, developed in 1952, have been promulgated in an attempt to establish greater uniformity among the states in sewage treatment plant design and operation. As noted in Tables II, III, and IV, in addition to the 10 signatory states, the standards have been voluntarily adopted either in their entirety or in part by at least 10 others.

These standards stipulate that where a public health hazard may otherwise be created, provisions for disinfection of sewage plant effluent shall be required.

State Standards

At least 29 state agencies are authorized by statute to establish standards of water quality (8) to protect legitimate water uses, including protection of the public health, public water supplies, industry, agriculture, fish and wildlife, and recreation.

The basic criterion used by most states in establishing the need for sewage disinfection is the effect of the discharged wastes on the receiving water body and its subsequent uses. Instances where sewage disinfection is required might include those numerous facilities in close proximity to public water supply intakes, bathing and other recreational areas, and shellfish propagation areas, or, as in Arizona, where crop irrigation (not for human consumption), and, in Illinois, where dairy cattle pastures also are involved.

Continuity of Chlorination

In many of the coastal states protection of shellfish growing areas is an important concern. In such places, continuous chlorination may be required (as in Oregon) or it may be provided only on a seasonal basis (as in Connecticut, where the practice is employed between May 15 and September 15).

Seasonal chlorination of sewage effluents also is especially popular at plants that discharge into or near bathing and other seasonal recreational areas (for example, Lake Erie) where shellfish and drinking water supplies are not involved.

Some states (such as Alabama, Florida, Idaho, Oregon, Texas, Virginia, and West Virginia) advocate provision for chlorine disinfection as a general policy irrespective of local considerations. The continuity of practice is a function of use. In other states (such as Georgia, Iowa, Kansas, and Oklahoma) chlorine disinfection is only occasionally required. Similarly the process is only little used in states (such as North Dakota) where complete secondary treatment is preferred, and in others (such as Montana and Wyoming) where lagoons and oxidation ponds are increasingly employed. A few other states (for example, California, Colorado, and Louisiana) have no official policy relative to sewage disinfection.

In a few states (such as Rhode Island) limiting coliform concentrations of effluent discharges are defined; the majority of states, however, tend to favor the establishment of stream standards, in contrast to effluent standards. Some states (such as New York) specify effluent disinfection to effect necessary bacterial reductions; others do not specify the means (South Carolina, for example, requires that wastes "must be managed" in such a way that the MPN of coliforms at water supply intakes does not exceed 5,000 per 100 ml, and immediately above bathing areas, 1,000 per 100 ml).

Point of Chlorine Application

As indicated earlier, the benefits of chlorine in sewage treatment are manifold. The point or points at which chlorine is applied depend, in large part, on the purpose for which it is used and the type of treatment employed.

Up-sewer chlorination generally is employed to control septicity and odors, thereby decreasing the load on the sewage treatment plant. For the purpose of disinfection, this point occasionally is employed where screening is the only form of subsequent treatment. This, however, is not an efficient means of disinfection because chlorine cannot fully penetrate the bacteria-laden sewage solids. For this reason, up-sewer chlorination for disinfection is rarely advocated and only infrequently employed.

Application of chlorine at the sewage treatment plant influent chamber ahead of the settling unit (that is, pre-chlori-

nation) is the preferred means of disinfection at primary sewage treatment plants. Coupled with settling, this treatment provides for removal of settleable sewage solids and, if properly managed, affords contact time sufficient to effect the desired bacterial reductions. At some primary treatment plants facilities for post-chlorination also are provided, especially where complete disinfection is indicated. (Such facilities are routinely encouraged by New Hampshire authorities.) Post-chlorination alone in conjunction with primary treatment generally is not recommended because of the increased chlorine demand of decomposing solids and colloidal, soluble chlorine-demanding substances often associated with settling processes.

Application of chlorine at the terminal point of secondary sewage treatment plants is intended primarily for disinfection. In some instances a separate chlorine contact basin is provided immediately preceding effluent discharge; or, currently more popular, chlorine is applied immediately ahead of the final settling unit if sufficient detention is provided and recirculation is not practiced. Pre-chlorination for disinfection should not be provided in conjunction with secondary treatment processes.

Only a few states specify the point of chlorine application, although many routinely consider this design feature in their plan review activities. The "Ten State Standards" contains no reference to the subject except the preference that pre-chlorination be employed at primary treatment plants. Florida, Virginia, and some other states routinely recommend that means for both pre- and post-chlorination be provided. In Alabama means for pre-chlorination are routinely recommended for all plants, with other points of application provided as needed.

In Michigan (where the practice of two-stage disinfection is becoming very common except at activated sludge plants and some trickling filter plants) all primary treatment plants have provisions in their design for two-stage disinfection. In Wisconsin post-chlorination is required at all primary treatment plants (except those that discharge into the Mississippi River) and at secondary treatment plants as necessary, whereas in Pennsylvania the reverse situation applies.

In Idaho terminal disinfection is the minimum requirement for all municipal sewage treatment plants; in many other states, also, this is a routine minimum recommendation.

Operation

Chlorine Dosage

The amount of chlorine required to disinfect sewage is variable; only broad generalizations can be made. The character of a community's waste varies from time to time and may differ considerably from those of other communities. Furthermore, the degree of treatment indicated may be different, depending on the condition of the receiving water at the time of discharge and the requirements of the regulatory authority. Because each community's waste presents its own problem of determining a chlorine dosage that will assure the desired results, it is essential that chlorine application be regulated as often as necessary to insure efficient and economical operation. Only by frequent determination of chlorine residuals can the dosage rate (and, thus, the efficacy of sewage chlorination) be satisfactorily established.

The chlorine dosage rate is dependent on the volume of flow and the chlorine demand of the waste, and varies with the composition, age and temperature of the waste, the contact time, the presence or absence of industrial wastes, and other factors. Although cognizant that chlorine requirements can be ascertained only by the determination of residual chlorine, several states have adopted regulations or recommenda-

TABLE II.—Summary of Estimated Average Chlorine Dosage Capacity (in ppm) Recommended or Required for Disinfection of Sanitary Sewage

Treatment	By 10 State Standard[1]	By FSIWA[2]	State[3]				
			Ala.	Conn.	Fla.	N.J.	Ore.
Pre-chlorination[4]	20–25	—	—	—	20–25	—	—
Raw sewage	—	6–12[5] 12–25[6]	—	24	—	30	24
Primary effluent	20	—	15	24	20	20	18
Tr. filter effl.	15	3–10	5	15	15	15	12
Act. sludge effl.	8	2–8	5	6–8	10	10	6
Sand filter effl.	6	1–5	—	6–8	10	10	6

[1] Includes: Del., Ill., Ind., Iowa, Ky., Me., Mich., Minn., Mo., Mont., Nebr., Nev., N.Y., Ohio, Okla., Pa., S.Dak., Utah, W.Va., and Wis.

[2] "Manual of Practice No. 4" (6).

[3] Others: Ala.: to produce a minimum residual of 1.0 ppm at average design flow; Idaho: about 5 ppm chlorine except for raw or septic sewage; R.I.: To produce an effluent having no coliforms in 1/10 ml sewage; N.H. and Tenn.: about 20 ppm chlorine for primary plants, 10 ppm chlorine for secondary plants; Tex.: max rate of 200 lb chlorine per mg sewage treated; Vt.: 15 to 30–40 ppm chlorine; Va.: capacity for both pre- and post-chlorination, i.e., 35 ppm chlorine (15 ppm disfn; 20 ppm odor control); and Wash.: about 5–20 ppm, depending on use (except raw or septic sewage).

[4] Mechanically cleaned tanks.

[5] Fresh sewage.

[6] Septic sewage.

tions for chlorinator capacities to insure equipment capability for adequate disinfection at periods of maximum flow and maximum chlorine demand. These are summarized in Table II. The "Ten State Standards" further recommend that the equipment should be of sufficient capacity to be capable of producing a chlorine residual of 2.0 ppm in the final effluent.

Contact Time

As evidenced by the data in Table III, opinions differ relative to required contact period with chlorine for disinfection. State authorities frequently recommend a minimum contact period of 15 and 30 min at peak and average flow, respectively, after thorough mixing.

In 1947, according to Faber (6), at least 36 states required or recommended that a contact tank be provided; 9 states found detention on some other basis equally suitable. However, some states (such as Alabama) currently lean toward elimination of contact tanks and are becoming more lenient with regard to minimum contact time with chlorine.

The "Ten State Standards" offer no recommendation on the use of chlorine contact tanks, but specify a minimum of 15-min contact (after thorough mixing) at peak hourly flow or maximum rate of pumpage.

Chlorine Residuals

Effective disinfection requires that there be a chlorine residual after a suitable contact period. Faber (6) indicated that in 1947 at least 33 states specified the amount of residual chlorine which should be present at the end of a specified contact period. About 80 per cent specified a minimum chlorine residual of 0.5 ppm or less; 21 states specified a minimum residual of 0.5 ppm.

As indicated in Table IV, at the present time considerably less significance apparently is placed by the various states on the definition of minimum chlorine residuals. Except insofar as

TABLE III.—Summary of Minimum Chlorine Contact Period Recommended or Required for Disinfection of Sanitary Sewage

Contact Time (min)	Design Basis	State
15[1]	Peak hourly flow; or max rate of pumpage	Del., Ill., Ind., Iowa, Me., Mich., Minn., Mo., Mont., Nebr., N.Y., N.Dak., Ohio, Okla., Pa., S.Dak., Utah, W.Va., Wis.
15	Average flow	Md.
15	Maximum flow	Calif., Conn.,[2] Mass., Mich., N.H., Tenn.
20	Average flow	Ala., Idaho, R.I., Wash.
20–30	Average flow	Ky.
30	Average flow	Calif., Kans., N.J., N.Y., Ore., Tenn., Va.
10–15	Not specified	La.
15	Not specified	Miss., Wis.
20	Not specified	Nev., N.Dak., Tex.
20–30	Not specified	Vt.
30	Not specified	Wyo.,
Not spec.	—	Ark., Colo., Ga., N.Mex., S.C.

[1] "Ten State Standards."
[2] 30 min preferred.

the "Ten State Standards" recommend that chlorinator capacity be sufficient to provide a 2.0-ppm residual in the effluent, no specifications are offered with regard to actual operating chlorine residuals in order to effect satisfactory disinfection. Despite the practical importance of chlorine residual tests, the only positive means of establishing the effectiveness of sewage disinfection is by measuring the bacterial population after treatment. This index of sanitary quality is determined by the dilution technic, expressed as the most probable number of coliforms (MPN), or by the membrane filter technique. The statistical approach of Eliassen *et al.* (9) to sewage disinfection and chlorinator control is based on the maintenance of a fixed chlorine residual to obtain a stipulated MPN 50 per cent of the time as determined by a statistical evaluation of the results of four series of ten chlorination experiments.

TABLE IV.—Summary of Recommended or Required Chlorine Residuals (in ppm) When Sewage Disinfection is Employed

Chlorine Residual (ppm)	State
Trace	La., Miss., Ore.
0.5	Fla., Idaho,[1] N.Y., Tex., Wis.
1.0	Md., Mass., Nev.
1.0–2.0	Ariz., Va.
2.0	Wyo.
Other	R.I.[2]
Not specified	Ala., Ark., Calif., Colo., Conn., Del., Ga., Ill., Ind., Iowa, Kans., Ky., Me., Mich., Minn., Mo., Mont., Nebr., N.H., N.J., N.Mex., N.C., N.Dak., Ohio, Okla., Pa., S.C., S.Dak., Tenn., Utah, Vt., Wash., W.Va.

[1] Maximum.
[2] R.I. requires residual such that coliforms are absent in 0.1 ml of sewage.

Summary

Use of chlorine for disinfection constitutes its most important application in the field of sewage treatment, although its uses for other purposes are numerous. The utility of chlorine as a waste treatment chemical has been firmly established over the past half century, and there is some evidence that it will increase even more remarkably in the next few years.

In recent times there has been established a trend toward more uniformity in the principles of water pollution control, but specific provisions vary considerably among the states. Because

water pollution control and resources conservation concern so many interest groups, an increasing number of states are forming separate water pollution control commissions. These commissions, or boards, coordinate the activities of all agencies involved in water use and act as arbiters in cases where conflicts of interest exist; in the majority of states they share responsibility with health authorities insofar as pollution abatement is concerned.

In addition, where interstate waters are involved, many states have organized cooperative agencies or compacts. In many instances these, as well as the various states themselves, have developed systems of stream classification and have defined standards of water quality depending on use. The basic criterion for establishing the need for sewage disinfection is the effect of the discharged wastes on the receiving water body and its subsequent uses. Accordingly, disinfection is practiced continuously, intermittently, or not at all, depending on local considerations and subject to the requirements of the appropriate regulatory authority involved.

About 75 per cent of the states have some regulation or recommendation relative to chlorine equipment capacity. Thirty-one states have adopted the 2.0-ppm minimum chlorine residual recommendation of the "Ten State Standards"; five states define the capacity in terms of the type of treatment employed; the remainder use some other arbitrary index or make no recommendation.

Opinions differ as to required contact period for disinfection. About one-half of the states require or recommend a minimum detention of 15 min at maximum flow; the remainder vary up to 30 min at average flow.

In contrast to earlier indications, considerably fewer states define minimum chlorine residuals of effluent where disinfection is employed. Thirty-three states have no official policy concerning this matter; the remainder vary from a trace to a maximum of 2.0 ppm after 30-min contact.

Although fairly extensive laboratory and plant observations have been reported, blind and widespread adherence to an arbitrary standard for residual chlorine, that is based on conditions applicable only under certain fairly specific conditions, reflects neither prudence nor efficiency on the part of regulatory authorities or plant officials. Furthermore, the considerable variations in chlorination objectives, depending on the condition of the receiving water body and its subsequent uses, preclude establishment of rigid chlorine residual requirements.

Meeting a certain chlorine residual requirement at the end of a given contact period is merely assuring satisfaction of the chlorine demand of the sewage. The value of maintaining a fixed chlorine residual is based principally on local demonstrations of the effect of such practices on desired bacterial kills and state requirements of effluent quality. No state defines surface water quality in terms of residual chlorine content although, as previously noted, some states arbitrarily define minimum chlorine residuals that actually may reflect either under- or over-treatment of effluents, in accord with adopted resource quality classifications or stream standards.

References

1. Porges, R., "United States Sewage Treatment Practices During the Early Twentieth Century." THIS JOURNAL, **29**, 12, 1321 (Dec. 1957).
2. "Sewage Treatment Facilities in the United States." *Eng. News-Rec.*, **115**, 7, 224 (Aug. 15, 1935).
3. "A Summary of Census Data on Sewerage Systems in the United States." *Public Health Repts.*, **57**, 12 (Mar. 20, 1942).
4. Thoman, J. R., "Statistical Summary of Sewage Works in the United States." *Public Health Repts.* (Apr. 1950).

5. Thoman, J. R., "Statistical Summary of Sewage Chlorination Practice in the United States." THIS JOURNAL, **22**, 9, 1128 (Sept. 1950).
6. "Chlorination of Sewage and Industrial Wastes." Manual of Practice No. 4, Federation of Sewage and Industrial Wastes Assns., Washington, D. C. (1951).
7. "Standards for Sewage Works—Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, Wisconsin." Upper Mississippi River Board of Public Health Engineers and Great Lakes Board of Public Health Engineers (May 1952).
8. Nemerow, N. L., and Wilson, W. C., "Recent Legislation Affecting Industrial Waste Disposal." *Ind. Eng. Chem.*, **50**, 2, 95A (Feb. 1958).
9. Eliassen, R., Heller, A. N., and Krieger, H. L., "A Statistical Approach to Sewage Chlorination." *Sewage Works Jour.*, **20**, 6, 1008 (1948).

MEETINGS OF INTEREST

1958

Oct. 20–24 **National Safety Congress and Exposition,** Conrad Hilton Hotel, Chicago, Ill. R. L. Forney, Secretary, National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Oct. 22–25 **National Society of Professional Engineers,** St. Francis Hotel, San Francisco, Calif. J. A. Sontheimer, Secretary, California Society of Professional Engineers, C/O St. Francis Hotel, San Francisco, Calif.

Oct. 27–31 **American Public Health Association,** Kill Auditorium, St. Louis, Mo. Dr. Berwyn F. Mattison, Executive Secretary, 1790 Broadway, New York 19, N. Y.

Oct. 29–31 **Southeastern Water Resources Conference,** Shore Club Hotel, Miami Beach, Fla. John W. Wakefield, Coordinating Chairman, Department of Water Resources, The Capitol, Tallahassee, Fla.

Nov. 6–7 **Water Resources Conference,** State College of Washington, Pullman, Wash. William H. Knight, Technical Extension Services, Washington State Institute of Technology, Pullman, Wash.

Dec. 7–10 **American Institute of Chemical Engineers,** Netherland Plaza Hotel, Cincinnati, Ohio. F. J. Van Antwerpen, 25 West 45th St., New York 36, N. Y.

AMINO ACIDS IN TREATED SEWAGE IN INDIA

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Observation (1) that the effluent from the activated sludge process was practically free from amino acids suggested an examination of the effluents from other systems of sewage treatment for their amino acids. At the same time it appeared that the available information on the amino acid composition of sewage and sludges was not adequate (2)(3)(4)(5)(6). Thus, there was no evidence of the distribution of free and total amino acids in sewage and sludges, the extent of their removal from sewage during treatment by different methods, and related aspects. On these aspects some evidence has now been collected at Bangalore, and in this paper an account of the observations on the amino acid contents of different sewage effluents is given and the significance of the results discussed.

Sewage Effluents Examined

The effluents examined represent those from chemical clarification, mechanical and biological filtration, septic tank, activated sludge process, and from natural purification of flowing sewage. The details regarding the collection and preparation of the materials for analytical studies are briefly described hereinafter.

Chemical Clarification

A 5-l sample of raw sewage from the Institute sewage works was collected and treated with enough alum to clarify the liquid. The clarified supernatant was carefully filtered through filter paper (Whatman No. 1) and the filtrate was evaporated on a water bath. The quality of the effluent, the nitrogen content of the material, and other details are given in Table I, which includes similar information about other effluents.

Mechanical Clarification

The raw sewage was drawn through an unglazed porcelain tube of ⅛ in. thickness and ⅞ in. internal diameter. The filtration was effected by means of a suction pump attached to a water tap.

Laboratory Biological Filters

The filtering media in the fine filters used consisted of (a) granite pieces (½ in. size), (b) sand from a river bed, (c) sand fraction passing a 20-mesh but retained on a 40-mesh sieve, (d) sand fraction passing a 40-mesh but retained on a 60-mesh sieve, and (e) sand fraction passing a 60-mesh but retained on a 100-mesh sieve. These materials were taken in glass tubes of uniform size (1.75 in. diameter) to occupy a 1-ft column in each case. The filters were treated daily with equal volumes of the raw sewage (250 ml each, the rate of filtration being adjusted uniformly). The filters were "ripened" by recirculating the sewage 7 times a day. This was continued for three weeks, after which sewage was allowed to percolate through the different materials once a day. Operation of a similar set of filters was described earlier in connection with the study of the behavior of the filtering media (7). The effluent from each filter was dried and the dried materials were examined.

TABLE I.—Quality of the Sewage Effluents

Treatment	N in Solids (%)	Turbidity*	Oxygen Absorption (ppm)		Dissolved Oxygen (ppm)	Purif.† (%)
			3 Min	4 Hr		
Chemical clarification with alum	1.92	14	6.0	13.2	6.2	62.5
Mechanical filtration (unglazed porcelain tube)	1.18	20	7.6	—	5.8	49.0
Biological filtration:						
Granite (½-in. size)	1.90	88	10.5	24.8	4.8	34.4
Sand (river bed)	0.82	40	4.8	12.3	7.2	69.9
Sand (20–40 mesh)	0.72	47	5.2	14.2	6.6	67.2
Sand (40–60 mesh)	0.65	28	4.2	10.4	7.8	74.4
Sand (60–100 mesh)	0.98	60	6.2	16.8	5.4	58.9
Septic tank	2.14	102	14.4	30.2	0.4	27.2
Activated sludge	—	18	2.4	10.2	8.2	90.8
Natural purification, flowing sewage:						
Sewage flowing down land at gradient of 1 in 50 (at 1.29 miles from outfall)	0.22	20	2.6	8.8	7.4	91.4
Sewage flowing down land at gradient of 1 in 100 (at 4.75 miles from outfall)	0.18	22	2.1	8.8	7.6	92.5

* Values obtained by using Klett Summerson colorimeter with 420 filter.
† On 3-min oxygen absorption.

Septic Tank

The effluent from the septic tank at the Institute was collected and dried for examination.

Activated Sludge Process

The effluent obtained by aerating the raw sewage with 15 per cent activated sludge was collected and dried for the test.

Natural Purification of Flowing Sewage

Practically the entire volume of sewage from the town of Bangalore is allowed to flow from three outfalls on the outskirts of the town. The three natural channels taking the sewage have different gradients; viz., 1 in 50, 1 in 100, and 1 in 800. The sewage in the channel having the 1-in-50 gradient, as it traverses a distance of 1.29 miles, undergoes biological action and is used for washing purposes by *dhobis*. Similarly, the sewage in the channel having the 1-in-100 gradient is biologically transformed, but for a distance of 4.75 miles; here also the purified effluent is used for washing purposes by the people in the neighborhood (8). These naturally treated effluents were also examined for their amino acid contents. Analyses were made of corresponding raw sewage and effluent samples.

Preparation for Chromatographic Analysis

Amino Acids in Free Form

For the estimation of free amino acids present in sewages and effluents, the liquids were dried on a water bath at 60°C. In each case the dried material (0.4 g) was taken in a conical flask and extracted thrice with acidified 95 per cent alcohol (10 ml at a time). Extraction by this method has been found to effect desalting (9). The alcoholic extract was treated and mixed with three times its own volume of chloroform, thoroughly shaken, and allowed to separate. The aqueous

layer separated was decolored with animal charcoal and the decolored extract was concentrated to 1 ml. A portion of it (100 to 150 μl) was used for spotting on the chromatogram.

Total Amino Acids

For the estimation of total amino acids, the dried material (0.3 g) was hydrolyzed with 25 ml 6N hydrochloric acid at 15-lb pressure for 6 hr in an autoclave, filtered, and evaporated to dryness. The residue was dissolved in water and evaporated, the evaporations being repeated with addition of water from time to time until all the hydrochloric acid was removed. Finally, the residue was dissolved in 10 ml of distilled water, and a portion of it (5 to 30 μl) was used for spotting.

Some of the amino acids (*e.g.*, lysine and histidine; serine, glycine, and aspartic acid; threonine and glutamic acid; and methionine and valine) overlap on the circular paper chromatogram. In each case lysine, histidine, serine, glycine, aspartic acid, and threonine were identified individually by running two-dimensional chromatograms, which were developed in one direction with phenol saturated with water in coal gas atmosphere and in the other direction with butanol-acetic acid-water. Methionine was identified by using platinic iodide reagent, and valine in the methionine-valine band was identified by oxidation of methionine, using hydrogen peroxide (10).

TABLE II.—Amino Acids in Raw Sewage and Effluent Obtained by Clarification of Sewage with Alum (as mg per g of the dried solids)

Amino Acid	Raw Sewage		Alum—Clarified	
	Free Form	Acid Hydrolysate	Free Form	Acid Hydrolysate
Cystine	0	1.4	0	0
Lysine and histidine	Trace	5.1	Trace	2.7
Arginine	0.06	4.6	0.05	2.4
Serine, glycine, and aspartic acid	0.04	12.5	0.02	6.4
Threonine and glutamic acid	0.07	13.3	0.05	6.9
Alanine	0.03	6.7	0.03	2.9
Proline	0	0	0	0
Tyrosine	0.09	1.7	0	0
Methionine and valine	0.18	8.5	0.12	2.8
Phenylalanine	0.10	5.1	0.06	2.0
Leucines	0.13	6.7	0.10	1.8
Total	0.70	65.6	0.43	27.9

TABLE III.—Amino Acids in Raw Sewage and Effluent Obtained by Drawing Sewage Through Unglazed Porcelain Tube (as mg per g of the dried solids)

Amino Acid	Raw Sewage		Filtered Through Unglazed Porcelain	
	Free Form	Acid Hydrolysate	Free Form	Acid Hydrolysate
Cystine	0	4.3	0	2.9
Lysine and histidine	Trace	5.1	Trace	2.2
Arginine	0.04	5.7	0.03	3.6
Serine, glycine, and aspartic acid	0.02	14.6	0.02	7.9
Threonine and glutamic acid	0.03	11.3	0.03	6.8
Alanine	0.05	7.3	0.02	3.9
Proline	0	0	0	0
Tyrosine	0.09	2.3	0.04	Trace
Methionine and valine	0.05	0.9	0.03	5.4
Phenylalanine	0.02	6.3	Trace	4.2
Leucines	0.06	8.2	0.03	5.7
Total	0.36	75.0	0.20	42.6

Method of Analysis

In the detection and determination of the amino acids the circular paper chromatographic technique (11)(12)(13) was employed. The quantitative determination of the amino acids was carried out by eluting the color of the ninhydrin-stained bands of amino acids separated on the chromatogram with 75 per cent ethanol containing copper sulfate and comparing the color intensity with that of the known

TABLE IV.—Amino Acids in Raw Sewage and Effluents Obtained by Filtration of Sewage Through Granite and Various Fractions of Sand (as mg per g of the dried solids)

Amino Acid	Raw Sewage	Effluent from Filtration of Sewage Through				
		Granite 4-in. Size	Coarse Sand	Sand 20–40 Mesh Sieves	Sand 40–60 Mesh Sieves	Sand 60–100 Mesh Sieves
(*a*) Free Form						
Cystine	0	0	0	0	0	0
Lysine and histidine	Trace	Trace	Trace	Trace	0	Trace
Arginine	Trace	Trace	Trace	Trace	Trace	Trace
Serine, glycine, and aspartic acid	0.13	0.09	0.04	0.04	0.02	0.06
Threonine and glutamic acid	0.18	0.13	0.08	0.06	0.06	0.07
Alanine	0.09	0.05	0.02	0.02	0.01	0.03
Proline	0	0	0	0	0	0
Tyrosine	0.08	0.02	0	0.02	0	0
Methionine and valine	0.22	0.16	0.08	0.04	0.01	0.03
Phenylalanine	0.14	0.08	0.02	0.02	0.01	0.04
Leucines	0.17	0.11	0	0	0	0
Total	1.01	0.64	0.24	0.20	0.11	0.23
(*b*) Acid Hydrolysate						
Cystine	3.1	1.9	1.4	1.0	0	0
Lysine and histidine	8.2	6.8	3.9	2.8	1.7	2.7
Arginine	6.1	4.5	2.1	1.8	1.2	1.6
Serine, glycine, and aspartic acid	9.4	7.5	3.7	2.8	1.7	3.2
Threonine and glutamic acid	8.9	7.1	2.5	2.0	1.2	2.8
Alanine	5.1	4.2	1.7	1.5	1.0	1.6
Proline	0	0	0	0	0	0
Tyrosine	2.4	1.6	Trace	Trace	Trace	Trace
Methionine and valine	9.1	8.2	2.2	2.6	1.5	2.8
Phenylalanine	8.6	6.9	1.6	2.0	1.4	1.7
Leucines	4.2	3.1	0	0	0	0
Total	65.1	51.8	19.1	16.5	9.7	16.4

standard solution of the amino acid run on the same paper.

Experimental Results

The results of analysis of the different effluents and the corresponding sewages for their amino acids, both free and total, are given in Tables II to VII.

Discussion

The analytical studies have shown that raw sewage contains a considerable amount of practically all the essential amino acids. The samples of sewage obtained from the sewage works at the Institute were found to contain 0.36 to 1.01 mg of free amino acids and 65.1 to 91.3 mg of total amino acids per gram of the solids. The samples of town sewage as discharged at the outfalls on the outskirts of Bangalore were found to contain 1.05 to 1.12 mg of free amino acids and 116.4 to 128.1 mg of total amino acids per gram of the solids.

Analysis of the raw sewage samples for the amino acids in the free form did not show tryptophane. If it was present in the combined form, it should have been destroyed during acid hydrolysis.

TABLE V.—Amino Acids in Raw Sewage and Septic Tank Effluent (as mg per g of the dried solids)

Amino Acid	Raw Sewage		Septic Tank Effluent	
	Free Form	Acid Hydrolysate	Free Form	Acid Hydrolysate
Cystine	0	3.9	0	3.9
Lysine and histidine	Trace	5.5	Trace	5.1
Arginine	Trace	6.7	Trace	6.7
Serine, glycine, and aspartic acid	0.04	18.3	0.03	10.1
Threonine and glutamic acid	0.01	9.5	0.01	8.0
Alanine	0.02	7.0	0.01	5.2
Proline	0	0	0	0
Tyrosine	0.06	3.5	0.06	3.7
Methionine and valine	0.17	15.1	0.12	8.7
Phenylalanine	0.16	11.1	0.13	8.3
Leucines	0.11	10.7	0.10	7.1
Total	0.57	91.3	0.46	66.8

TABLE VI.—Amino Acids in Raw Sewage at Kempambudhi Outfall and Effluent at 1.29 Miles from the Outfall* (as mg per g of the dried solids)

Amino Acid	Raw Sewage at Outfall		Effluent at 1.29 Miles†
	Free Form	Acid Hydrolysate	Acid Hydrolysate
Cystine	0	5.7	0
Lysine and histidine	Trace	7.9	0
Arginine	Trace	7.6	0
Serine, glycine, and aspartic acid	0.06	19.4	Trace
Threonine and glutamic acid	0.12	24.8	Trace
Alanine	0.07	11.9	Trace
Proline	0	0	0
Tyrosine	0.16	6.4	0
Methionine and valine	0.24	14.5	0
Phenylalanine	0.33	16.8	Trace
Leucines	0.14	13.1	0
Total	1.12	128.1	

* Channel having 1-in-50 gradient.

† Effluent at 1.29 miles did not contain any amino acids in free form.

TABLE VII.—Amino Acids in Raw Sewage at Magadi Outfall and Effluent at 4.75 Miles from the Outfall* (as mg per g of the dried solids)

Amino Acid	Raw Sewage at Outfall		Effluent at 4.75 Miles†
	Free Form	Acid Hydrolysate	Acid Hydrolysate
Cystine	0	4.8	0
Lysine and histidine	Trace	9.7	0
Arginine	Trace	8.9	0
Serine, glycine, and aspartic acid	0.08	17.6	Trace
Threonine and glutamic acid	0.17	18.1	Trace
Alanine	0.04	9.3	Trace
Proline	0	0	0
Tyrosine	0.06	5.8	0
Methionine and valine	0.20	15.7	0
Phenylalanine	0.22	14.4	0
Leucines	0.28	12.1	0
Total	1.05	116.4	

* Channel having 1-in-100 gradient.

† Effluent at 4.75 miles did not contain any amino acids in free form.

The effluents obtained by chemical clarification of sewage, and by purely mechanical filtration of sewage by drawing it through an unglazed porcelain tube and from the septic tank were found to contain considerable amounts of the amino acids originally present in the sewage. These effluents were found to undergo putrefactive changes on exposure to air.

The amino acids in the effluents from filters containing different materials varied, depending on the efficiency of the filter. At the same time, none of the filters studied yielded an effluent free from amino acids. In such a short time as a few minutes during downward filtration of sewage through a 1-ft column of even the most efficient filtering material, it might be expected that the amino acids in the liquid could not be entirely removed from it by its merely flowing down the

filter a few times. Nevertheless, there were appreciable differences in regard to the amounts of amino acids in the effluents from different filters, the effluent from the filter containing 40- to 60-mesh material showing the least amount of amino acids.

Continued observations on the quality of the effluent from a well-managed sewage farm at Madura (S. India) have shown that the clear effluent supports a variety of microorganisms, particularly protozoa of the species of *Carchesium* and *Epistylis*, and higher forms of life such as fish (14). Recent observations showed that the land-filtered sewage effluent contained amino acids.

In this connection it is of special interest to note an observation made in 1909 at Manchester, England, by Fowler (15), who observed a considerable growth of *Carchesium* at the base of a secondary percolating filter treating the effluent from primary contact beds: "The effluent from the percolating filter is, except for a small amount of suspended humus, clear and bright, non-putrefactive, and practically saturated with dissolved oxygen. Nitrification is well advanced, and the 4-hr oxygen test and albuminoid ammonia are below 'the limits of impurity' of the Mersey and Irwell Joint Committee. Yet considerable development of *Carchesium* takes place in the outlet channel, with, as has been found, simultaneous diminution in the dissolved oxygen content."

Unlike the effluents from chemical clarification, mechanical filtration, septic tank, and different biological filters, the effluent from the activated sludge process (being practically free from amino acids) was not found to support protozoa such as the colonial *Vorticellids*.

Another point of considerable interest, both from scientific and practical points of view, is the practically complete removal of the amino acids from the town sewage as it runs over a short distance of 1.29 miles along the natural channel having a gradient of 1 in 50. The behavior of this naturally purified effluent was found to be similar to that of the activated sludge process.

Summary

Effluents from 10 systems of sewage treatment, both artificial and natural, were examined for their amino acid composition. Although the effluents from chemical clarification, mechanical filtration, septic tank, and biological filters were found to contain varying amounts of amino acids (the most efficient filter giving the least amount), the effluents from the activated sludge process and from natural purification of flowing sewage at Bangalore were found to be practically free from amino acids.

References

1. Pillai, S. C., Mohan Rao, G. J., Krishnamurthy, K., and Prabhakara Rao, A. V. S., "Amino Acids in Sewage and Activated Sludge." *Current Sci.*, **22**, 235 (1953).
2. Rudolfs, W., and Heinemann, B., "Growth-Promoting Substances in Sewage and Sludge. III. Vitamin C, Carotene, Amino Acids, Fatty Acids and Naphthyl Compounds." *Sewage Works Jour.*, **11**, 4, 587 (July 1939).
3. Corti, U. A., "Contribution to the Protein Chemistry of Town Sewage." *Trav. Congr. Ind. Limnol.*, **10**, 119 (1948, 1949); *Water Poll. Abs.*, **24**, 159 (1951).
4. Wuhrmann, K., "The Amino Acid Content of Treated and Untreated Sewage." *Biol. Abs.*, **27**, 677 (1953).
5. Corti, U. A., "Chemical Studies of the Proteins in Activated Sludge from Sewage Disposal Plants." *Schweiz. Z. Hydrol.* (Switzerland), **15**, 152 (1953); *Water Poll. Abs.*, **28**, 232 (1955).
6. Zymny, E., "Determination of Amino Acids in the Sewage of a Treatment

Plant." *Stadtehygiene*, **5**, 12 (1954); *Water Poll. Abs.*, **28**, 342 (1955).

7. Pillai, S. C., and Mohan Rao, G. J., "Influence of Filtering Medium on Clarification of Sewage in Biological Filters." *Science and Culture*, **18**, 289 (1952).
8. Pillai, S. C., Mohan Rao, G. J., Prabhakara Rao, A. V. S., Natarajan, C. V., and Madappa, I. B., "Protozoal Development and Natural Purification of Flowing Sewage." *Indian Med. Gaz.*, **88**, 507 (1953).
9. Baliga, B. R., Krishnamurthy, K., Rajagopalan, R., and Giri, K. V., "A Simple Method for Desalting Biological Fluids for Chromatography." *Jour. Indian Inst. Sci.*, **37A**, 18 (1955).
10. Giri, K. V., Krishnamurthy, K., and Venkatasubrahmanyan, T. A., "Circular Paper Chromatography. Part II. Amino Acid Analysis of Proteins." *Jour. Indian Inst. Sci.*, **34A**, 209 (1952).
11. Giri, K. V., and Rao, N. A. N., "Circular Paper Chromatography. I. A Technique for the Separation and Identification of Amino Acids." *Jour. Indian Inst. Sci.*, **34A**, 95 (1952).
12. Giri, K. V., Radhakrishnan, A. N., and Vaidyanathan, G. S., "Some Factors Influencing the Quantitative Determination of Amino Acids Separated by Circular Paper Chromatography." *Anal. Chem.*, **24**, 1677 (1952).
13. Giri, K. V., Krishnamurthy, K., and Venkatasubrahmanyan, T. A., "Quantitative Determination of Amino Acids Separated by Circular Paper Chromatography." *Current Sci.*, **21**, 44 (1952).
14. Pillai, S. C., Rajagopalan, R., and Seshachar, B. R., "On the Occurrence of Protozoa in Land-Filtered Sewage Effluent." *Current Sci.*, **16**, 254 (1947).
15. Fowler, G. J., "The Quality of Effluents in Relation to Standards." *Jour. Roy. San. Inst.*, **30**, 513 (1909).

PROFESSIONAL OPPORTUNITY

The Department of Sanitary Engineering of the District of Columbia is accepting applications for the position of Sewage Treatment Plant Shift Superintendent.

Desired qualifications include college degree in sanitary or civil engineering and previous experience in sewage treatment plant operation. The starting salaries for these positions are $4,490 to $7,510, depending on experience.

This is a Civil Service position as a Shift Superintendent in a high-rate activated sludge treatment plant of a design capacity of 290 mgd. Benefits include paid annual leave and sick leave, group insurance, retirement and other employee benefits.

Those interested may send a complete summary of education, experience and personal data to Hugh A. Schreiber, Superintendent, D. C. Sewage Treatment Plant, 5000 Overlook Avenue, S. W., Washington 24, D. C.

Industrial Wastes

AERATOR DESIGN AND DEVELOPMENT

By Stefan A. Zieminski, Frederick J. Vermillion, Jr., and Bruce G. St. Ledger

Respectively, Associate Professor, Research Engineer, and Research Assistant, Chemical Engineering Department, University of Maine, Orono, Me.

Aeration is an important step in the treatment of sewage by bio-oxidation and in many industrial fermentation processes. It has also been successfully used as a means of supplying oxygen to streams polluted by oxidizable matter (1).

The major portion of the costs of this operation is expended in the compression and dispersion of large quantities of air into small bubbles. In the systems encountered in present-day aeration practice only a comparatively small percentage of the oxygen supplied is absorbed by the liquid. Any means resulting in improvement of the oxygen absorption efficiency will reduce the costs of the installation and decrease the energy requirement of the process.

From the many factors affecting the rate of absorption of oxygen the area of contact between the liquid and the air appears to be of major importance. An economical aeration system should therefore produce, at low energy requirement, a high degree of dispersion of air in the treated liquid.

One of the main objectives of this work was to investigate systems which if successfully developed would satisfy the above requirement. In the preliminary phase of the investigation it was decided to investigate a system which in principle would consist of a high-speed, rotating disc or cylinder provided with perforations at its periphery. The air would be introduced axially into the aerator and leave at its circumference. One or more aerator discs (or cylinders) mounted on a common frame and driven by a submersible motor would constitute an aeration unit that could be easily located at the bottom of a stream or reservoir. Since in this type of aerator the air bubbles are formed mainly by the shear at the disc boundary it was expected that the energy requirement for driving the aerator would be comparatively low.

The material discussed in this paper covers the first part of the investigation which is being carried on in the laboratories of the Department of Chemical Engineering of the University of Maine.

Pilot-Scale Tests

The pilot-scale aeration tests were conducted in an absorption column 61 inches high and 22 inches in diameter. In all runs the air was introduced into the water through the perforations of a rotating brass disc mounted in the bottom of the column.

The purpose of these experiments was to obtain some information regarding the relative influence on aerator efficiency of such variables as: (a) number of openings, (b) diameter of openings, (c) arrangement of openings,

TABLE I.—Summary of Pilot Scale Absorption Tests

Run	No. of Openings	Diameter of Opening (in.)	Arrangement of Openings*	Diameter of Disc (in.)	Air Flow Rate (cu ft/min)	Peripheral Speed (ft/min)	Efficiency—O_2 Absorbed (%)
1	38	0.02	1 row at circumference	8	0.286	1,800	27.1
					0.568	1,800	24.7
2	75	0.02	1 row at circumference	8	0.294	1,800	29.8
					0.572	1,800	25.3
3	150	0.02	2 rows at circumference	8	0.288	1,800	32.4
					0.570	1,800	28.5
4	300	0.02	4 rows at circumference	8	0.291	1,800	32.4
					—	—	—
5	150	0.0135	2 rows at circumference	8	0.294	1,800	33.3
					0.580	1,800	27.1
6	300	0.0135	4 rows at circumference	8	0.296	1,800	32.9
					0.584	1,800	28.7
A	41	0.02	1 row at circumference	8	0.294	1,871	30.2
					0.581	1,871	25.7
B	41	0.02	1 row on top of disc ($\frac{1}{4}$" from edge)	8	0.296	1,871	29.1
					0.585	1,871	24.9
C	40	0.02	2 rows at circumference	$4\frac{1}{2}$	0.297	1,965	32.0
					0.58	1,965	26.9

* In all runs shown in this table the thickness of the disc was one inch.

(d) shape and diameter of the disc, (e) peripheral speed, and (f) air flow rate. This information was not only necessary for the design of the large-scale experimental aerator but also for making necessary provisions in its construction to allow a closer investigation of some of the above-mentioned variables.

The experiments were carried out in sodium sulfite solutions at air flow rates of 0.3 and 0.6 cfm. The height of the liquid above the level of the aerator was 51 in. and was kept constant in all the tests.

Some of the more pertinent results are presented in Table I. In Runs 1 to 4 the number of openings in the aerator disc was increased from 38 to 300 without changing the other experimental conditions. It can be seen that the increase in the number of openings up to 150 improves the efficiency of absorption. The importance of this improvement can be best seen by comparing Runs 1 and 3. In Run 3 (150 openings), at an air flow rate of 0.57 cfm, the efficiency of absorption was 28.5 per cent, that is 1.4 per cent higher than the efficiency in Run 1 (38 openings) at one-half the air rate of Run 3. These results indicate that it is possible to increase the air capacity of the aerator without decreasing the efficiency of absorption by increasing the number of openings.

Comparing the results of Runs 3 and 4, it appears that a further increase in the number of openings has no effect on the efficiency of absorption. A possible explanation of this fact is that with a larger number of openings the pressure drop became too small to insure a continuous flow through all the openings in the aerator.

In Runs 5 and 6 the diameter of the

openings was decreased from 0.02 to 0.0135 in. Comparison of the results of these tests with those of corresponding Runs 3 and 4 with larger openings show that this comparatively large change in the cross-section of the openings had practically no influence on the efficiency of absorption. The above is in good agreement with the results of absorption tests conducted with rotating glass nozzles of widely different diameters (2). Although it appears that the size of the openings is not a major design factor, it is felt that the results obtained are not sufficient to warrant any definite conclusion in this respect.

Runs A and B were conducted under analogous conditions except for the arrangement of openings in the disc. In Run B the openings were drilled in the top of the disc, while in Run A the air was passed through openings drilled at the circumference. In addition to the above two runs, more experiments were conducted to determine the importance of the spacing and location of the openings of the aerator. However, neither of the arrangements investigated showed any distinct advantage as far as the efficiency of absorption was concerned.

In Run C the diameter of the disc was decreased to 4½ in. but the speed of rotation was increased to maintain approximately the same peripheral speed as in Run A. The absorption efficiencies in Run C were slightly higher than in Run A, which might have been partially due to the somewhat higher peripheral speed in Run C.

The results of these tests are of special interest because they indicate that the size of the aerator may be considerably decreased without much effect on the efficiency of absorption, provided the peripheral speed remains the same.

Large-Scale Tests

The main objective of the large-scale aeration experiments was to investigate the economical feasibility of the system, especially from the point of view of its energy requirement.

Emphasis has been put on evaluation of the influence of peripheral speeds, air flow rates, and depths of immersion of the aerator on the efficiency of oxygen absorption and energy consumption. The maximum air flow rate used in the experiments was 10 cfm. In the course of the experiments it was found that higher air flow rates could have been used without affecting the total energy requirement of the system. However, a further increase in the air flow rate would have shortened the duration of tests so as to decrease the accuracy of the sampling procedure.

The tests were conducted in a 10,000-gallon tank in the Hydraulics Laboratory of the University of Maine.

Description of the Experimental Equipment

A schematic diagram of the test equipment is shown in Figure 1. The air was supplied to the aerator by four diaphragm-type reciprocating compressors, each of a capacity of 2.8 cfm. The compressors were connected to the air manifold by means of Valves 1 to 4. When smaller air flow rates were required only two or three compressors were used at a time. With this type of compressor the air was free of oil. The air was filtered through a carborundum filter to remove dust and other impurities in suspension. To secure good uniformity of flow and prevent pulsations in the air line, the air leaving the filter was first passed through a surge tank. The flow of air was metered by a rotameter. The pressure and temperature of the air were measured by an open-tube mercury manometer and thermometer. The rate of flow of air was adjusted to the required value by means of Valves D and E.

The air leaving the rotameter was introduced into the aerator through a stationary gland and a hollow shaft.

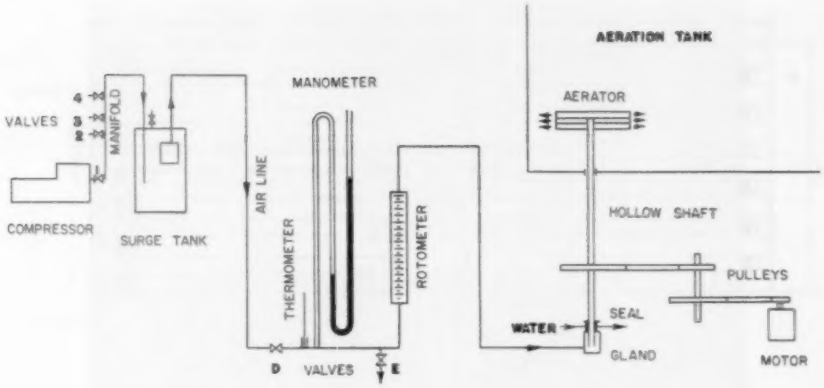

FIGURE 1.—Equipment diagram for aeration experiments.

In order to prevent air leakage from the gland a water seal was provided in the upper part of the gland. A system of balanced pressures (not shown in Figure 1) was used to keep the water pressure in the seal equal to the air pressure in the gland. The aerator shaft was made of steel tubing 1.25 in. OD and 0.5 in. ID, copper clad from the inside to prevent rusting. The aerator drive consisted of a 1-hp electric motor and a system of pulleys which allowed regulation of the speed of the shaft within the range of 0 to 500 rpm, corresponding to peripheral speeds of from 0 to 2,880 fpm. The aerator, mounted at the top of the shaft, was placed 2 ft above the bottom of the aeration tank. Figure 2 shows the position of the aerator in the tank and the corresponding dimensions. The aeration tank used in the tests had over-all dimensions of 12.5 by 8.3 by 14.0 ft (height). It was provided

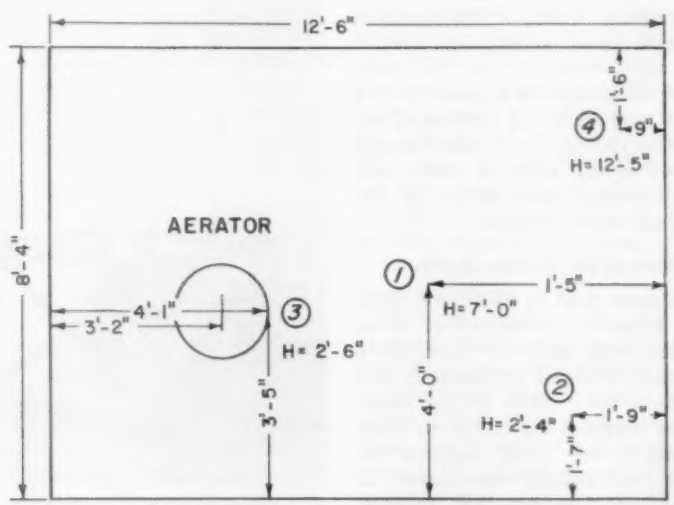

FIGURE 2.—Aeration tank plan showing location of sampling points.

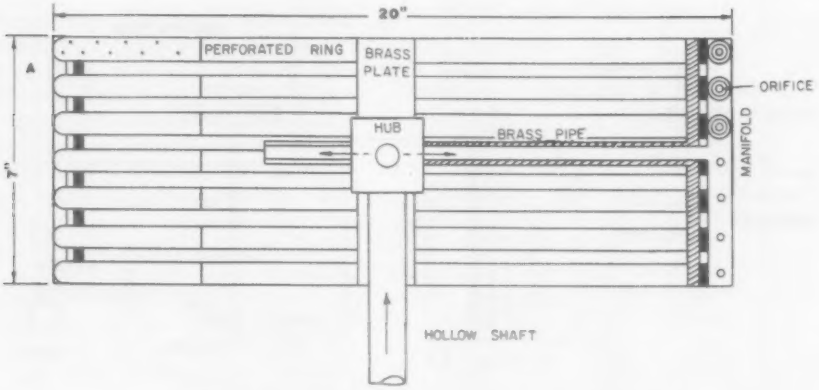

FIGURE 3.—Side view and section of aerator.

with a level indicator and the usual water and sewer connections. To prevent rusting the inside of the tank was covered with a coat of corrosion resisting paint. The maximum capacity of the tank was over 10,000 gallons. The only place accessible from underneath the tank, through which the shaft of the aerator could have been inserted, was the manhole located in the corner of the tank. The position of the aerator was therefore determined by the local conditions and not by other considerations. However, the aeration test results seem to indicate that it would have been better to have mounted the aerator at a point farther from the tank walls. A portion of the air bubbles did not have room enough to spread in the bulk of water and some coalescence was visible at the walls closest to the aerator.

Description of the Rotary Aerator

The aerator used in this work (Figures 3, 4, and 5) consisted of seven perforated rings made of ¾-in. lucite tubing and arranged horizontally one above the other. Each of the lucite tubes was mounted separately on brass rings which were held together by means of four vertical brass plates. A clearance of ¼ in. was left between the lucite rings. The air was introduced through a hollow shaft into the hub, from which it was distributed into two of the four brass pipes that formed

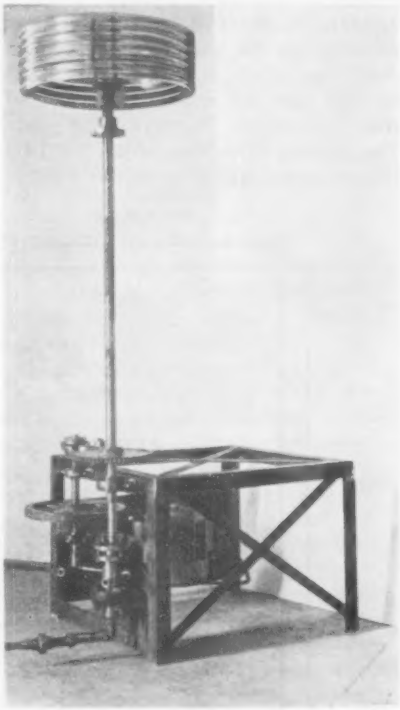

FIGURE 4.—Aerator and driving mechanism.

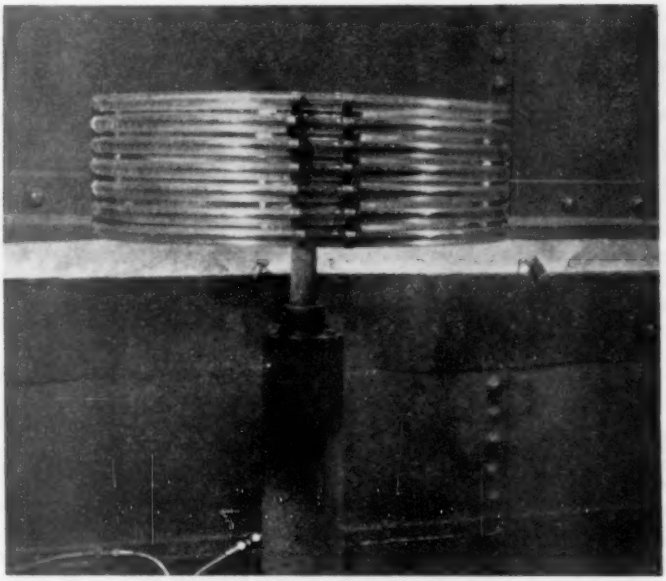

FIGURE 5.—Aerator after installation.

the spokes of the aerator. The air leaving the pipes was then introduced into two air manifolds through which it entered the perforated rings.

To insure a uniform distribution of air into the rings, small brass orifices were mounted into each outlet from the manifold. In this way each of the rings was supplied with air by means of four orifices. This arrangement gave a very uniform air distribution, even at low air flow rates when the influence of the hydrostatic head was more pronounced.

Each of the rings was provided with 220 holes drilled in two horizontal rows. The diameter of the holes was 0.02 in. and the distance between the holes in any row was ½ in. The two rows were arranged so as to give a triangular pitch with a vertical distance between holes of 5/16 in.

In the design of the aerator stress was put on a uniform distribution of bubbles in order to decrease the danger of coalescence. The size and the spacing of the holes were selected on the basis of data obtained in the pilot-scale tests. It is, however, possible that the diameter of the holes could have been increased without affecting the efficiency of absorption (2).

The main reason for providing clearances between the aerator rings was to improve the water flow pattern across the aerator. It was expected that in this way a better distribution of air bubbles could be effected. However, the absorption tests conducted with the aerator showed beyond doubt that the clearances not only did not affect the efficiency of absorption, but materially increased the energy required to drive the aerator. This point will be discussed later.

Since at the time the aerator was designed, not enough design data were available, provisions were made in the construction of the aerator to allow for future modifications. The use of lucite rings was of special advantage in this respect. It offered a possibility of an easy change in the number of rows of holes and in their size and spacing.

Whenever possible, attempts were made to streamline some parts of the aerator to decrease its energy requirement.

Procedure

All the aeration tests presented in this report have been conducted with Orono city water. The analysis of the water is given in Table II.

The efficiency of absorption was determined directly from the increase in the dissolved oxygen concentration and the air flow rate. This method requires that there be no biochemical uptake of oxygen while the test is being conducted. For this reason the water was stabilized by a continuous 53 hr aeration.

During the aeration period absorption tests were conducted under analogous experimental conditions to determine the progress of stabilization. At the end of the stabilization period a sample of the water was collected in six BOD bottles. The bottles were then suspended in the water in the tank to keep the samples at the water temperature. At different time intervals, covering the total period of the aeration tests, a sample was removed from the tank and analyzed for DO content. The total decrease in the DO concentration was found to be about 0.2 ppm.

Since the duration of one aeration test was only about 30 min the error caused by the oxygen uptake was well beyond the standard deviation of the Winkler method.

TABLE II.—Analysis of Orono City Water

Constituent	Quantity
Turbidity	0*
Color	60†
Nitrogen	0.400*
Free NH_3	0.008*
Nitrites	0*
Nitrates	0.01*
Hardness	14.0*
pH	6.3
Chlorides	2.0*

* ppm.
† Color units.

Before each aeration test the water was deoxygenated by adding sodium sulfite. During deoxygenation, nitrogen was passed through the aerator to insure a uniform distribution of sulfite in the mass of water. The amount of sulfite used was slightly in excess of that required for complete deoxygenation. Cobalt chloride was added in the amount equivalent to 0.04 ppm of Co to catalyze the reaction of oxidation of sulfite (2) and thus accelerate the process of deoxygenation.

The sampling system used in this work consisted of four 3/8-in. brass tubes installed at the locations shown in Figure 2. During the test the water was allowed to flow continuously through the sampling tubes into 300 ml BOD bottles. In time intervals ranging from 2 to 10 min the samples were collected and immediately analyzed for DO (3). To evaluate the reliability of the sampling procedure an aeration test was conducted in a dilute solution of sodium sulfite. The samples were taken simultaneously from the four sampling points and analyzed for sodium sulfite. The results are plotted in Figure 6. Except for the Sampling Point 3 the results show good consistency. Sampling Point 3 was installed directly above the aerator and it was difficult to avoid entrainment of bubbles into the sampling tube. This was probably the reason of the lower values and poorer consistency of results obtained with this sampling point. It was therefore disconnected and not used in the aeration tests.

Since the results obtained using Sampling Points 1, 2, and 4 showed good consistency, Point 1 was arbitrarily selected for DO determination.

The rate of flow of air to the aerator was measured by a Fischer and Porter Flowrator meter, capacity 1 to 11 cfm. The calibration of the instrument was checked by passing known weights of nitrogen through the meter. The air flow rates given in this report are ex-

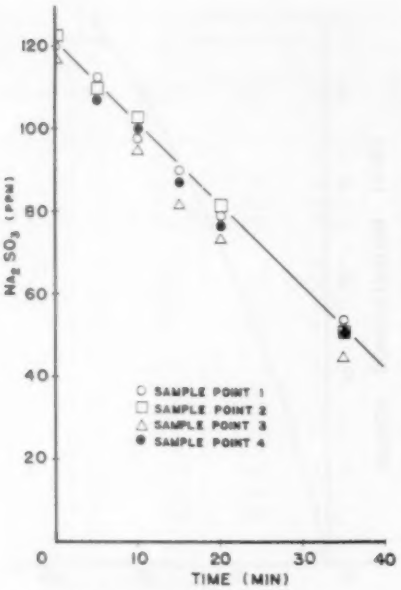

FIGURE 6.—Sodium sulfite concentrations at various sampling points.

pressed in cfm (32°F, 1 atm), dry. The air leakage of the whole installation was determined several times during the course of the work. The average leakage amounted to about one per cent of the total flow and a corresponding correction has been introduced in the calculation of the efficiency of oxygen absorption. The air flow rates used in the tests were 5.8, 8.1, and 10.4 cfm.

The power required to drive the aerator was measured in each test. It was expressed as a net power requirement, that is, the difference between the total power required to drive the aerator and the power requirement of the driving mechanism itself. The values thus calculated have the advantage of being independent of the design and construction of the driving mechanism. The power requirement for compression of the air was calculated on the basis of an ideal single-stage compressor and adiabatic compression. From the above two power items the total net energy requirement was calculated and expressed in Kwhr per pound of oxygen dissolved. This is therefore the combined energy requirement (compressor and aerator drive) for dissolving one pound of oxygen under the existing conditions of operation. In the discussion of the results an over-all mechanical efficiency of 75 per cent was tentatively assumed to approximate the total actual energy requirement of the system.

Calculation of the Rate of Aeration

The rate of absorption of oxygen was calculated from the equation:

$$\frac{dc}{dt} = \frac{10^6}{w} K_L a (C_i - C_L) \ldots . (1)$$

in which

c = DO concentration, ppm;
t = the time of aeration, hr;
w = weight of water in tank, lb;
K_L = oxygen transfer coefficient, based on the liquid film resistance, lb of oxygen per hour per square foot per unit concentration difference in ppm;
a = instantaneous contact area of bubbles, sq ft;
C_i = equilibrium concentration of oxygen, ppm;
C_L = concentration of oxygen in water at any time, ppm.

Assuming C_i and a as independent of time, integration of Eq. 1 gives:

$$K_L a = \frac{2.3}{10^6} w \times \left[\frac{\log (C_i - C_o)/(C_i - C_L)}{t} \right] \ldots (2)$$

in which C_o is the initial DO concentration in ppm at time t_o.

The assumption that C_i and a are independent of time is not fully justified. The surface area of the bubble varies because of changes in bubble volume caused by decrease in the hydrostatic head as the bubble rises in

the column of water and by the loss of oxygen from the bubble. The influence of the loss of oxygen on the surface area of the bubble is, however, comparatively small since it affects only a small fraction of the total volume of the bubble. As far as the influence of the hydrostatic head is concerned, it remains constant in each experiment. It may therefore be assumed that the total surface area of the bubbles remains practically constant during the course of a given aeration test.

The bubble surface area was not determined in this work and is therefore included in the combined constant, K_La.

Referring to the equilibrium concentration, C_i, it is evident that its value will change with time as the result of changes in the partial pressure of oxygen within the bubble, caused by decrease in hydrostatic head and absorption of oxygen during its ascent.

Attempts were made to express C_i, as well as a, as a function of time for use in Eq. 1. However, no satisfactory solution to this problem has been found (4)(5). According to Carver (4) for water depths normally encountered in aeration practice the changes in the variables above are sufficiently small to warrant the use of average values.

In this report the average C_i was calculated from the equilibrium concentration at the level of the aerator and at the water surface.

In the calculation of K_La the values of C_L from the absorption curves (C_L vs. t) were used to plot the logarithmic term in Eq. 2 against time. The numerical value of the slope of the resulting straight line was then used in Eq. 2 to calculate K_La. The rates of aeration at different DO concentrations were computed by means of Eq. 1. In some runs the calculations were checked by graphical differentiation of the aeration curves. Satisfactory agreement of the results was obtained.

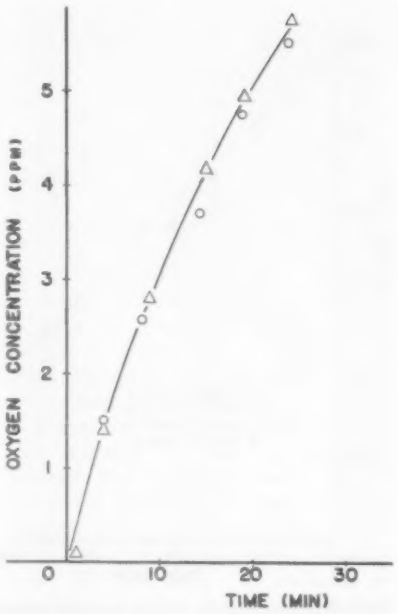

FIGURE 7.—Results of reproducibility tests.

Reproducibility Tests

To check the reproducibility of the experimental procedure two absorption tests were conducted under analogous experimental conditions. In both tests the rate of flow of air was 8.1 cfm, the peripheral speed of the aerator, 890 fpm, and the temperature of water, 20°C. The height of the water level in the tank was the same in both tests. The results are plotted in Figure 7.

As can be seen from the figure, the reproducibility of the results was very satisfactory, especially in the region of DO concentrations between 0 and 4 ppm.

The experimental procedure described herein was therefore adopted without change in the aeration tests presented in this paper.

Discussion of Results

It has already been mentioned that the peripheral speed is one of the major

TABLE III.—Effects of Peripheral Speed and Air Flow on Oxygen Absorption

Group	Run	Air Rate (cfm)	Peripheral Speed (fpm)	Water Temp. (°C)	Hydrostatic Head (ft)	Weight of Water (lb)	Efficiency—O_2 Absorbed (%)			
							0*	1*	2*	3*
I	1	5.8	0	20.8	11.2	86,150	8.8	8.0	7.1	6.2
	2	5.8	586	20.2	10.7	83,900	13.5	12.6	11.2	9.8
	3	5.8	890	21.0	10.6	82,500	20.8	18.8	16.6	14.4
	4	5.8	1,150	21.0	10.4	81,800	26.2	23.4	20.6	17.9
II	5	8.1	0	21.0	10.6	82,700	6.9	6.3	5.7	5.0
	6	8.1	586	20.8	10.7	83,300	12.9	11.6	10.4	9.1
	7	8.1	890	21.0	10.5	82,100	18.8	16.9	15.0	13.1
	8	8.1	1,150	21.0	10.4	81,600	23.6	21.0	18.6	16.2
III	9†	10.4	0	21.0	10.5	82,500	5.9	5.3	4.7	4.2
	10	10.4	586	21.0	10.6	82,900	11.8	10.6	9.5	8.3
	11	10.4	890	21.0	10.5	81,900	17.2	15.5	13.7	12.0
	12	10.4	1,150	21.5	10.4	81,400	20.8	18.7	16.5	14.4
IV	A	8.12	890	21.0	10.5	82,100	18.8	16.9	15.0	13.1
	B	7.99	890	21.5	7.2	60,800	16.3	14.6	12.8	11.1
	C	8.18	890	21.5	3.7	39,600	11.3	10.1	8.8	7.6

* DO level (ppm).
† Calculated values.

factors determining the efficiency of oxygen absorption of the investigated system. An increase in the speed of the aerator improves the efficiency. However, as the speed increases so does the energy requirement for driving the aerator. Any gain in absorption efficiency resulting from the use of higher speeds must therefore be balanced against energy costs for optimum over-all efficiency.

Influence of Peripheral Speed

In order to evaluate the influence of speed on the absorption efficiency and energy requirement of the aerator three groups of aeration tests were conducted, each at a different air flow rate. The results are tabulated in Table III.

It can be seen that in each group of aeration tests the increase of the peripheral speed from 586 to 1,150 fpm almost doubled the efficiency of absorption. At lower air flow rates (5.8 cfm) and zero DO concentration, the efficiency increased from 13.5 per cent at 586 fpm to 26.2 per cent at 1,150 fpm. For the highest air flow rate (10.4 cfm) the same increase in speed resulted in an increase of absorption efficiency from 11.8 to 20.8 per cent. However, the relative increase of the efficiency with speed was practically the same in each of the three groups, indicating that the relative improvement of the efficiency produced by higher speeds is almost independent of the air flow rate used.

Speeds higher than 1,150 fpm have not been used in this work. The small-scale aeration test conducted in the previous year (2) showed that the increase of absorption efficiency with speed gradually becomes smaller at higher speed ranges.

Influence of Hydrostatic Head

The three runs shown at the bottom of Table III were conducted at the same peripheral speeds and air flow rates, but at varying hydrostatic heads. The purpose of the Group IV experiments was to evaluate the influence of the depth of immersion of the aerator on the absorption efficiency and energy requirement of the system.

The depth of immersion is an important factor influencing the economy of an aeration plant.

An increase in the depth of immersion improves the efficiency of absorption but at the same time increases the cost of compression. It has been found (4) that the oxygen transfer coefficient decreases with increasing depth of immersion. The rate of absorption is a maximum at the point of bubble formation, and takes on lower values during the rise of the bubble to the surface. It may therefore be expected that at higher depths of immersion the gain in efficiency of absorption would be too small to justify the increased costs of compression.

It can be seen from Table III, Group IV, that an increase of immersion from 3.7 to 7.2 ft substantially increased the efficiency of absorption, but a further increase to 10.5 ft had, however, a much smaller effect in this respect. The energy requirements for this group of tests are given in Table IV, Group IV. The data in Col. 11 show no improvement in the total energy requirement per pound of oxygen dissolved with increase of the depth of immersion from 7.15 ft (Run B) to 10.5 ft (Run A). In this case the advantage of higher absorption efficiency was just offset by the increased energy consumption for compression. The results indicate that there is a certain optimum depth of immersion for a given type of aerator. However, the limited number of tests conducted does not allow quantitative conclusions in this respect.

Influence of Aerator Shape

When designing the aerator a ¼ in. clearance between the rows of lucite rings was provided. It was expected that this would improve the distribution of air bubbles in the water and thus increase the efficiency of absorption. To check the effect of clearances on the efficiency of absorption a number of tests were conducted in which the clearances were covered by means of adhesive tapes. In all the tests the aerator with covered clearances (referred to as the shrouded aerator) gave the same efficiencies of absorption as those obtained with uncovered slots under otherwise the same conditions of operation. However, as far as the energy consumption is concerned the shrouded aerator showed a much lower energy requirement for driving, than the aerator with uncovered slots. The decrease in energy requirement was in some cases as high as 50 per cent.

To obtain more information regarding the influence of the aerator design on its energy requirement, a streamlined model was constructed retaining the same principal dimensions. The main difference between the original aerator and the streamlined model was the absence of air manifolds in the latter and the substitution of sharp-edged brass plates for the round spokes of the original aerator. The power requirement for driving the model was then measured at the speeds used in the experiments with the original aerator.

The limited time did not allow absorption tests to be conducted with the streamlined model. The energy requirement (per lb of O_2 dissolved) in this case was, therefore, calculated on the assumption that the efficiency of oxygen absorption is not affected by the changes introduced in the streamlined model.

The pilot-scale experiments conducted with discs of different shapes as well as those performed with the shrouded aerator support this assumption.

Comparison of Energy Requirements

The energy requirement data including those of the streamlined model are presented in Table IV. The run numbers given in Col. 2, Table IV, are the same as in Table III and correspond to the same aeration tests.

TABLE IV.—Energy Requirements of Rotary Aerator

1 Group	2 Run	3 Air Flow (cfm)	4 Speed (fpm)	Energy Requirements of Experimental Aerator (Kwhr/lb O_2 dissolved at zero DO)					Energy Requirements of Streamlined Aerator (Kwhr/lb O_2 dissolved at zero DO)		
				5 For Compression (adiabatic)	6 For Aerator (Slots uncovered)	7 For Aerator (Shrouded)	8 Total Theoretical (Col. 5+7)	9 Total Actual*	10 For Aerator	11 Total Theoretical (Col. 5+10)	12 Total Actual*
I	1	5.8	0	0.143	—	—	0.143	0.191	—	0.143	0.191
	2	5.8	586	0.093	0.099	0.048	0.141	0.188	0.0285	0.121	0.167
	3	5.8	890	0.060	0.32	0.209	0.269	0.359	0.106	0.166	0.222
	4	5.8	1,150	0.048	0.59	0.419	0.467	0.623	0.263	0.311	0.415
II	5	8.1	0	0.181	—	—	0.181	0.265	—	0.181	0.265
	6	8.1	586	0.098	0.074	0.036	0.133	0.178	0.021	0.119	0.159
	7	8.1	890	0.067	0.249	0.164	0.231	0.308	0.083	0.150	0.200
	8	8.1	1,150	0.054	0.467	0.331	0.385	0.514	0.208	0.262	0.350
III	9†	10.4	0	0.214	—	—	0.214	0.286	—	0.214	0.286
	10	10.4	586	0.109	0.065	0.031	0.140	0.187	0.019	0.128	0.170
	11	10.4	890	0.073	0.214	0.142	0.215	0.287	0.072	0.145	0.194
	12	10.4	1,150	0.061	0.415	0.294	0.355	0.474	0.185	0.246	0.328
IV	A	8.1	890	0.067	0.249	0.164	0.231	0.308	0.083	0.150	0.200
	B	8.0	890	0.053	0.294	0.194	0.247	0.330	0.099	0.153	0.202
	C	8.2	890	0.041	0.415	0.274	0.315	0.420	0.139	0.180	0.239

* Calculated on basis of 75 per cent efficiency of the compressor and aerator drive.
† Calculated value.

Comparing Col. 6 and 7 of Table IV, it can be seen that at lower speeds (586 fpm) the power requirement of the shrouded aerator was only 48 per cent of that required for driving the aerator with uncovered slots. With the increase in speed the difference became less pronounced, although even at the highest speed (1,150 fpm) the shrouded aerator required about 30 per cent less power as compared with the aerator with uncovered slots. These results are of special interest because they show that a comparatively small change in the construction of the aerator may produce a considerable change in the power requirement without affecting the efficiency of oxygen absorption.

It appears that peripheral speed or rather the resulting shearing force acting at the perforated surface of the aerator is the major factor affecting the absorption efficiency of the system. The shape and constructional details of the aerator itself seem to be of smaller importance in this respect.

Column 10 gives the energy requirements for driving the streamlined model. The results show that a further decrease in the energy consumption can be achieved by streamlining some parts of the aerator. Comparison of Col. 10 and 6 shows that at lower speeds (586 fpm) the streamlined model required only 29 per cent of the power necessary to drive the experimental aerator with uncovered slots.

In the experiments with the streamlined model the clearances between the lucite rings were left uncovered. From the experiments with the shrouded aerator it may be deduced that a further improvement could have been obtained by covering the clearances of the streamlined model.

The values given in Col. 9 and 12 have been calculated on the basis of 75 per cent mechanical efficiency of the

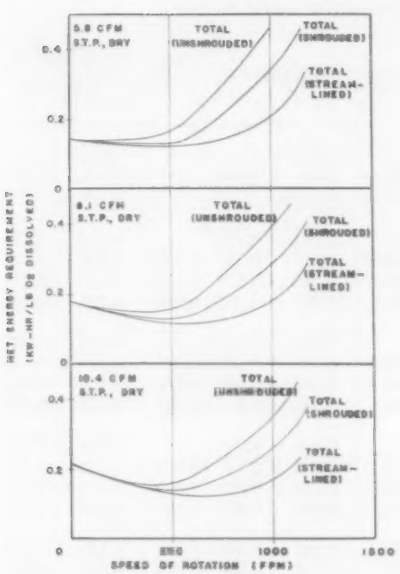

FIGURE 8.—Net energy requirements at zero DO concentration.

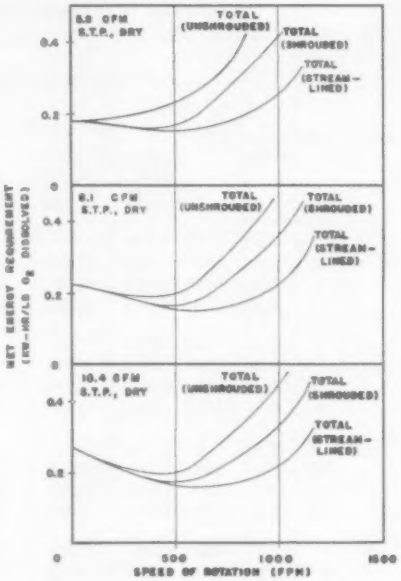

FIGURE 9.—Net energy requirements at 2 ppm DO concentration.

compressor and aerator drive. This was done in order to approximate the total actual energy requirement of the shrouded aerator (Col. 9) and the streamlined model (Col. 12).

The data from Table IV are presented graphically in Figures 8 and 9 and summarized in Table V.

Figure 8 shows the effect of the speed of the aerator on the total net energy requirement expressed in kwhr per lb of O_2 dissolved at zero DO concentration. The energy values plotted are the combined net energy requirements for driving the aerator and compressing (adiabatically) the air to the pressure equivalent of the depth of immersion of the aerator.

Each of these curves, except for the unshrouded aerator at low rates of air flow, shows a distinct minimum at a certain speed of rotation. These are the optimum speeds at which the total power requirement reaches its mini-

TABLE V.—Total Net Energy Requirements at Optimum Speeds at Zero and 2 ppm DO Concentration

Air Flow (cfm)	DO (ppm)	Shrouded Aerator			Streamlined Aerator		
		Optimum Speed (fpm)	Total Net Energy (Kwhr/lb O_2 dissolved)		Optimum Speed (fpm)	Total Net Energy (Kwhr/lb O_2 dissolved)	
8.12	zero	523	0.125	0.167*	590	0.118	0.158*
8.12	2	523	0.158	0.211*	590	0.148	0.197*
10.4	zero	523	0.140	0.182*	644	0.125	0.167*
10.4	2	523	0.169	0.226*	644	0.155	0.207*

* Calculated on the basis of 75 per cent mechanical efficiency of the compressor and the aerator drive to approximate actual energy consumption per lb of O_2 dissolved.

mum. Inspection of the charts for the medium (8.1 cfm) and the high (10.4 cfm) air flow rates shows that a considerable improvement in the total power requirement can be achieved by comparatively small changes in the design of the aerator. At optimum speeds in the medium and high air flow rates, shrouding of the aerator resulted in a decrease in the total energy consumption of 16 and 9 per cent, respectively. It also changed the position of the optimum speed moving it in the direction of higher speeds and therefore better absorption efficiencies.

The streamlined model showed a further improvement in this respect. At the highest air flow rate (10.4 cfm) the optimum speed of the unshrouded aerator was only about 440 fpm while with the streamlined model it was possible to increase it to about 650 fpm, improving in this way the absorption efficiency of the system.

The results obtained with the streamlined model should not be regarded as a limit beyond which no further improvement is possible in this system. On the contrary, it may be expected that a still further decrease in the energy requirement could be obtained by changes in the principal dimensions of the aerator.

The charts of Figure 8 show that the energy requirements of the shrouded aerator and the streamlined model remain practically constant and independent of the air flow used. This can be explained by the fact that at lower air flow rates the energy required for compression is smaller because of the higher efficiency of absorption while the energy required for driving the aerator is relatively higher as the result of the lower air capacity of the aerator. These two effects are compensatory in character thus decreasing the influence of the air flow rate through the aerator on the total energy requirement per pound of oxygen dissolved. This indicates that the air capacity could have been increased above 10 cfm without materially affecting the total energy requirement.

The upper chart of Figure 8 shows that the air flow rate of 5.8 cfm was much too small to warrant an economic operation of the aerator. Even with the streamlined model the energy consumption for driving the aerator was comparatively high and the total energy curve did not show a distinct minimum.

Figure 9 presents the energy requirement data at a DO concentration of 2 ppm.

The total energy data presented in Table V have been read from Figures 8 and 9 for optimum speed conditions.

Although the optimum speed corresponds to the minimum energy consumption, it is not necessarily the most economical speed of the aerator. The curves for the streamlined model show comparatively flat minima indicating that the speed of the aerator and therefore the absorption efficiency can be considerably increased without much affecting the energy requirement of the system.

The resulting advantages of higher absorption efficiencies, such as smaller air compressing plants and fewer aerator units, may more than offset the small increase in the energy requirement.

Conclusions

1. Under the experimental conditions used in this work the efficiencies of oxygen absorption varied from 12 to 26 per cent for the large-scale aerator and from 24 to 33 per cent for the pilot-scale aerator.

2. The increase of the peripheral speed of the large-scale aerator from 586 to 1,150 fpm almost doubled the efficiency of oxygen absorption, irrespective of the air flow rate used.

3. Covering of clearances between the aerator rings decreased the power requirement for driving the aerator by 30 to 50 per cent without affecting the efficiency of oxygen absorption. The

above indicates that comparatively small changes in the construction of the aerator may produce a considerable decrease in the power requirement for driving the aerator without affecting the efficiency of oxygen absorption.

4. Results obtained with the streamlined model show that a further decrease in the power requirement can be obtained by streamlining some parts of the aerator.

5. For a given set of experimental conditions, the total energy required to dissolve a unit weight of oxygen reaches a minimum at a certain optimum speed.

6. At the highest air flow rate used (10.4 cfm) and zero DO the total net energy requirement at optimum speed was 0.140 kwhr per pound of oxygen dissolved for the shrouded aerator as compared with 0.125 for the streamlined model.

7. In the case of the streamlined model the results of the tests showed that the speed of the aerator can be increased well above the optimum speed without materially affecting the total energy required to dissolve a unit weight of oxygen under otherwise the same experimental conditions. It may be expected that the advantage of higher absorption efficiencies at higher speeds would more than offset the small increase in the energy consumption.

Acknowledgments

The research described in this paper was supported in its entirety by a grant from the National Council for Stream Improvement Inc., New York. The authors wish to thank Dean A. S. Campbell and Dr. H. W. Gehm for helpful discussions and assistance. They also wish to thank Prof. L. C. Jenness for his assistance and interest in this work, and Prof. H. D. Watson for providing research facilities in his Department.

References

1. Wagner, H., "Die Künstliche Belüftung Kanalisierter Flüsse." Koblenz (1956).
2. Zieminski, S. A., and Cox, C. D., "Reduction of Sulfite Waste Liquor Pollution by Means of Artificial Aeration." Progress Report II. National Council for Stream Improvement Inc., New York, N. Y. (Nov. 1956).
3. "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes." 10th Ed., Amer. Pub. Health Assn., New York, N. Y. (1955).
4. Carver, C. E., Jr., "Absorption of Oxygen in Bubble Aeration." In "Biological Treatment of Sewage and Industrial Wastes," **1**, 149–171. Reinhold Publ. Corp., New York, N. Y. (1956).
5. Holroyd, A., and Parker, H. B., "Investigations on the Dynamics of Aeration." *Jour. and Proc., Inst. Sew. Purif.*, Part 4, 280 (1952).

POLLUTION CONTROL BY IN-PLANT MEASURES

A feature of the Annual Meeting of the American Institute of Chemical Engineers, Netherland Plaza Hotel, Cincinnati, Ohio, Dec. 7–10, will be a symposium on in-plant measures to control pollution. Among the topics discussed will be: modifications in pulping processes to reduce pollution; salvaging of blast furnace flue dust, rolling mill scale, and pickle liquor; water conservation and reuse in the petroleum industry; and by-product recovery in the fermentation industry.

ELEVATED TEMPERATURE EFFECT ON CITRUS WASTE ACTIVATED SLUDGE*

By Marshall H. Dougherty and Robert R. McNary

Florida Citrus Experiment Station, Lake Alfred, Fla.

During a pilot plant investigation of the treatment of citrus waste waters by the activated sludge process (1), it was reported that, at one point, the unit had become "so overloaded that the heat of its own activity raised the temperature so high that serious harm was done to the microorganism population." The temperature of the mixed liquor at that time rose from an average of 90°F (32.2°C) to a maximum of 106° (41°C). In view of this unusual happening, it was decided to find out what would be the effect of increased temperature on an activated sludge culture without the complications of an overloaded condition.

Apparatus

The apparatus used in this work was a modification of the small, laboratory scale, three-stage activated sludge unit used in previous work in this laboratory (2). Figure 1 shows a schematic drawing of the apparatus as modified for this study. It consisted of a raw waste supply tank A, a 12-l aeration tank B which had an electric heating tape wound around the outside, a clarifier C, and a final tank D to catch the effluent. The mixer E prevented the suspended solids in the raw waste from settling out, thus maintaining a more uniform waste supply for the system. The motor F drove the scrapers in the clarifier and G was a recording temperature regulator which recorded and regulated the temperature of the aerator liquor. A Sigmamotor pump metered the raw waste to the aerator from which it flowed by gravity to the clarifier. Another Sigmamotor pump withdrew sludge from the bottom of the clarifier and returned it to the aeration tank at the rate of two volumes of sludge to one volume of raw waste. Air was metered to the aerator at the rate of 0.3 cfm and dispersed through a piece of perforated, ¼-in. aluminum tubing. The effluent overflowed the rim of the clarifier to the effluent tank.

Procedure

A 24-hr supply of raw waste (16 l) was made up each morning by diluting orange juice to the desired concentration with tap water. During this study no inorganic nitrogen or phosphate was added as nutrient for the system. The system was not fed on Saturday or Sunday, but aeration was maintained at all times. Analyses for solids, pH, and sludge volume were run on the component parts of the system and chemical oxygen demand (COD) determinations were run on the raw waste and the effluent. All analyses were run daily except Saturday and Sunday. The COD analyses were run using the new colorimetric method developed in this laboratory (3). The temperature of the aeration liquor was varied as was desired or seemed necessary under the prevailing conditions. Microscopic examinations of the culture were made periodically to follow any changes in the microorganism population that might result from the changes in tempera-

* Cooperative research by the Florida Citrus Commission and Florida Citrus Experiment Station. Florida Agricultural Experiment Station Journal Series, No. 737.

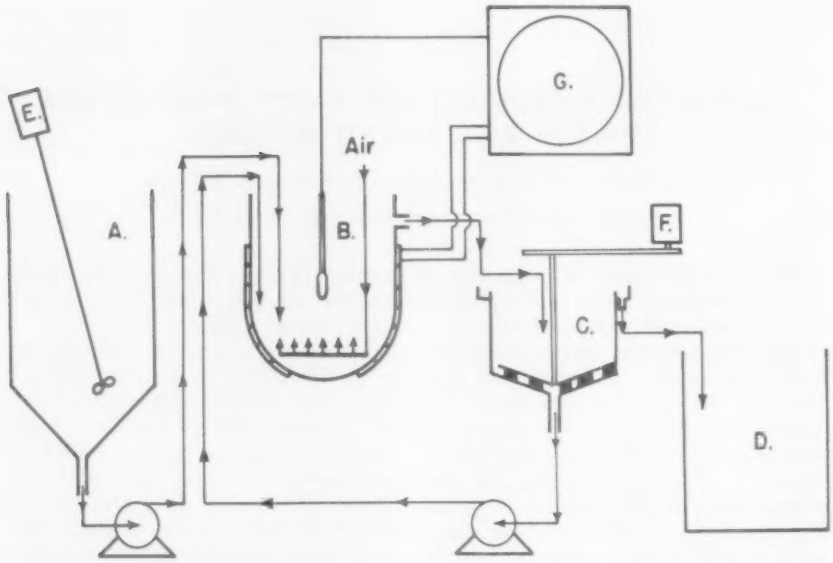

FIGURE 1.—Schematic diagram of laboratory apparatus used for the study of the effect of increased temperature on a citrus waste activated sludge culture.

ture. Sludge was withdrawn from the system only when it was necessary to maintain efficient settling in the clarifier. In this study the sludge volume was maintained between 25 and 30 per cent. The sludge volume was determined by centrifuging a 50-ml sample for five minutes in a clinical type centrifuge running at full speed.

Discussion

The culture used was that remaining from previous work (2) on the use of the excess sludge using the three-stage apparatus. The temperature of the aeration liquor under normal conditions and without any heat added was 21°C. The culture contained *Vorticellae*, *Paramecium*, *Arcella*, *Peranema*, and rotifers, plus a large number of bacteria.

The temperature was raised first to 30°C over a three-day period. The initial result was that some of the sludge floated on the surface of the clarifier and overflowed into the effluent, causing the COD of the effluent to increase from 50 to 230 ppm. At the same time the organisms originally present decreased in number and activity, and a large amount of *Sphaerotilus*-like, fibrous sludge appeared in the culture. After four days at 30°C the culture was once again settling well and the COD of the effluent had dropped back down to 55 ppm. Microscopically, however, the culture never did revert to the condition found at 21°C.

At this point the temperature was raised from 30° to 38°C in two days. This caused the same reaction as did the first large rise in temperature. The sludge once again floated and caused a high COD in the effluent. This time, however, all of the protozoa in the culture disappeared, except the *Peranema*. There was also a further increase in the amount of fibrous material present. After a week at this temperature, the system still contained floating sludge and the effluent had a high COD, so the temperature was lowered to 32°C. After three weeks

at this temperature the sludge was settling well and all of the protozoa indicative of a normal culture at this temperature were once again present. The fibrous material had also decreased considerably.

The temperature of the aerator liquor was then raised at the rate of 2°C per week to 38°C and thereafter 1°C every two days until a temperature of 46°C was reached. From 32° to 43°C the system operated very satisfactorily. The sludge settled well, giving a clear effluent having a COD of approximately 50 ppm. At 44°C the effluent became cloudy and the COD rose. At 46°C the sludge changed to a much lighter brown and the effluent became very cloudy. At the same time the organic solids in the effluent increased from 0.025 per cent to an average of 0.057 per cent and the COD increased to an average of 452 ppm. After three days of operation at 46°C with no signs of improvement, the system was shut down.

Microscopic examinations showed noticeable changes taking place in the culture as the temperature was increased. Above 36°C the population and activity of the protozoa were affected adversely. At 40°C the aerator liquor contained only very few rotifers *Paramecium* and *Arcella* and all appeared very sluggish. At 43°C the culture was devoid of all protozoa and the bacteria population was beginning to diminish. As mentioned before, at 46°C the quality of the treatment had deteriorated to the extent that the study was concluded.

Results

During this study of the effect of elevated temperature on the activated sludge culture it was found:

1. An activated sludge unit could be operated at a temperature as high as 36°C with no deleterious effect to the culture or the degree of treatment.

2. If, in approaching a temperature of 36° C, a rapid rise in temperature of 4° or 5°C occurred, a temporary period of unhealthy conditions was encountered but recovery took place if no further increase in temperature occurred.

3. As temperatures were increased above 36°C, the number and activity of the protozoa began to decrease until at 43°C the culture was devoid of all protozoa.

4. At a temperature of 46°C the degree of treatment obtained was poor and the experiment was concluded.

References

1. McNary, R. R., Wolford, R. W., and Dougherty, M. H., "Pilot Plant Treatment of Citrus Waste Water by Activated Sludge." THIS JOURNAL, **28**, 7, 894 (July 1956).
2. Dougherty, M. H., Wolford, R. W., and McNary, R. R., "Citrus Waste Water Treatment by Activated Sludge." THIS JOURNAL, **27**, 7, 821 (July 1955).
3. McNary, R. R., Dougherty, M. H., and Wolford, R. W., "Determination of the Chemical Oxygen Demand of Citrus Waste Waters." THIS JOURNAL, **29**, 8, 894 (Aug. 1957).

SPRAY IRRIGATION OF CERTAIN SULFATE PULP MILL WASTES*

By Stuart C. Crawford

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Several years ago, the management of Union Bag–Camp Paper Corporation considered expanding kraft pulp production from 400 to 600 tons per day at the Franklin, Va. plant. A major factor involved in this decision was concern over the disposal of liquid wastes.

The mill had been lagooning its effluent for a number of years with considerable success, resulting in a reduction of the total mill BOD load of approximately 65 per cent. However, it was realized that this expansion program would tax the lagoon facilities. In view of this, interest was expressed in spray irrigation as a possible means of disposal of certain segregated mill effluents.

The primary objective of this treatment method would be for the disposal of wastes from pulping operations, with secondary emphasis on agricultural use of the area involved. In other words, the project was regarded as a means of assimilating a definite quantity of mill wastes. If farming operations could also be carried on at the same time, this was felt to be a worthwhile objective.

Preliminary experiments were run and results indicated the ability of the soil to absorb even greater quantities of liquid than were proposed. Soil specialists were brought in at this stage of the investigation to make independent observations. On the basis of these findings it was determined that the idea was practicable and a decision to proceed with the project was made.

Wastes to be Sprayed

A mill survey program was begun to determine whether or not a significant portion of the pollution load could be sufficiently reduced in volume to make the project feasible.

The survey revealed that evaporator condensate, digester condensate, and dregs washings from the causticizing operations could be contained in slightly less than 1 mgd at a pulp production level of 600 ton per day. These wastes amounted to approximately 20 per cent of the total pollution load and were contained in about 5 per cent of the total waste volume.

These particular wastes were considered ideal for spray irrigation inasmuch as the BOD is due largely to entrained gases and the solids content is extremely low. It was further reasoned that these wastes would be amenable to lagoon and spray irrigation treatment and that little solids increase in the soil would result.

Under mill conditions prevailing during 1957 these wastes amounted to approximately 30 per cent of the total pollution load, contained in slightly more than 3 per cent of total flow.

This flow was diverted to a separate lagoon area, previously constructed. The lagoon has a surface area of approximately 15 acres with a mean depth of 12 ft and a maximum depth of 18 ft. The area is capable of holding some 60 mil gal which provides a 60-day retention based on the original

* Presented at the Annual Meeting of the Virginia Industrial Wastes and Sewage Works Assn.; Roanoke, Va.; Apr. 28–29, 1958.

TABLE I.—Comparison of Lagoon Influent and Effluent

Item	Influent (ppm)	Effluent (ppm)
Total solids	517	411
Loss on ignition	199	130
Residue	319	282
Dis. solids	315	361
Susp. solids	202	50
$CO_3^=$ alk.	188	0
HCO_3^- alk.	0	188
OH^- alk.	48	0
Soap hardness	10	66
5-day BOD	1,515	219
pH	9.6*	6.9*
Silica and insoluble matter	6.6	10.2
Iron	4.8	6.2
Aluminum	11.4	4.0
Calcium	18.0	15.2
Magnesium	6.8	5.9
Sodium and potassium†	123	164
Chlorides	35	11
Sulfates	34	53
Sulfides	23	1.8

* pH.
† As sodium.

estimate of waste quantity. The retention time was considerably greater under the 1957 conditions.

The results of lagooning are shown in Table I.

Irrigation System

A 2,100 gpm pump discharges lagoon effluent to a 14-in. header system, thence to a system of 6-in. laterals (Figure 1). Spray nozzles,* rated at 200 gpm at 70 psi, are spaced at 200-ft intervals along the laterals. Thus, each pair of laterals handles an area of something over 10 acres (2,200- by 200-ft). At this rate of application, one million gallons is applied to approximately 10 acres during one 8-hr period once a week. This is equivalent to about 0.45 in. per acre per hr. The weekly application amounts to 3.6 in. per acre.

The lagoon system was put into operation on March 1, 1957 and a month later the spray irrigation system was placed in service. The systems were operated according to the schedules shown in Tables II and III. There were 16 mil gal of wastes left in the

* Rainbird—Model 90—full circle (¾ in. × 7/16 in. × ¼ in.).

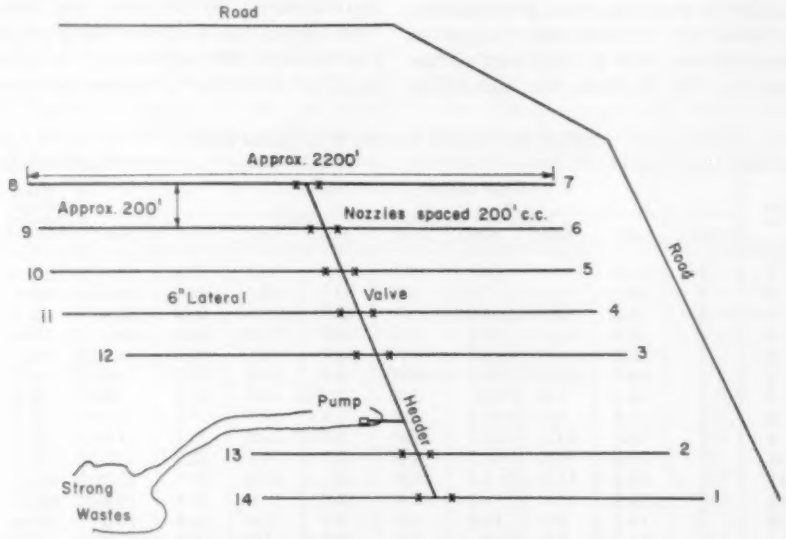

FIGURE 1.—Layout of spray irrigation system.

TABLE II.—Pumpage to Lagoon and Spray System

Month (1957)	Waste to Lagoon (mil gal)	Waste Sprayed (mil gal)
Mar.	22.3	—
Apr.	20.1	28.6
May	14.6	16.2
June	15.0	23.8
July	14.5	17.0
Aug.	15.5	18.9
Sept.	15.0	27.1
Oct.	18.5	30.8
Nov.	14.5	29.8
Total	150.0	191.4

lagoon after spray irrigation was discontinued on Dec. 1, 1957. Table II shows some discrepancy between the amount pumped to the lagoon and that supplied to the irrigated area. This is due to runoff from the irrigation plots flowing back to the lagoon. The runoff materially increased in the fall of the year when the growing season was over. The operation of the system is a responsibility of the pollution abatement department.

Rainfall data for two areas in the vicinity of Franklin, Va., are reported in Table IV. These data suggest a generally wet year for this part of the country. The Holland, Va., rainfall is thought to be more indicative of Franklin, Va. conditions existing during this period. Average rainfall in this vicinity normally ranges from 40 to 45 in. per year.

Results

Treatment Efficiency

During the irrigation period 150 mil gal of wastes were diverted to the lagoon. At a BOD concentration of 1,515 ppm this represents a lagoon loading of approximately 7,000 lb per day over the nine months period. The total BOD load of the mill during this period averaged about 23,000 lb per day.

The 16 mil gal remaining in the lagoon at the end of operations was released to the stream. This amounted to 48,000 lb of BOD; therefore, the net absorption by the system was 6,822 lb of BOD per day, or approximately 30 per cent of the total mill load.

In addition to the treatment already described for the strong mill wastes, the weaker wastes were lagooned in a separate area where a BOD removal of approximately 80 per cent took place. This lagoon has a surface area of approximately 300 acres with a mean depth of 10 ft and a maximum depth

TABLE III.—Liquid Loading on Irrigation Plots

Plot No.	Liquid Loading (in./acre/month)									Total Liquid Loading (in./acre)
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	
1	Irrigation system not in operation	14.2	5.9	26.1	13.7	9.8	15.7	17.9	19.6	122.9
2		18.1	8.0	7.8	3.9	9.1	15.7	19.6	19.6	101.8
3		18.2	10.4	14.2	11.8	12.7	18.6	20.4	19.6	125.9
4		16.4	11.4	11.8	9.8	12.7	19.6	19.6	19.6	120.9
5		16.2	11.4	13.7	7.6	12.7	15.7	19.6	19.6	106.9
6		14.3	11.2	13.7	10.0	9.8	15.2	15.7	11.8	91.7
7		14.5	7.8	16.7	7.8	7.3	15.7	11.8	7.8	89.4
8		14.5	7.8	16.7	7.8	7.3	15.7	7.8	7.8	85.4
9		14.3	11.2	13.7	10.0	9.8	15.2	15.7	11.8	91.7
10		16.2	11.4	13.7	7.6	12.7	15.7	15.7	15.7	99.1
11		16.4	11.4	3.9	11.8	12.7	19.6	19.6	15.7	111.1
12		18.2	10.4	14.2	11.8	12.7	18.6	20.4	19.6	125.9
13		18.1	9.0	15.5	9.8	9.1	3.9	19.6	19.6	103.6
14		14.2	2.0	0	9.8	9.8	3.9	17.9	19.6	77.2

TABLE IV.—Rainfall Data

Month (1957)	Rainfall (in.)	
	Como, N. C.	Holland, Va.
Mar.	4.72	4.47
Apr.	2.07	1.87
May	1.28	2.77
June	7.82	3.42
July	2.35	2.27
Aug.	4.74	5.32
Sept.	5.73	4.21
Oct.	3.84	4.53
Nov.	6.03	6.13
Total	38.58	34.99

of 20 ft. The weak-waste area had a capacity of about one billion gallons (50-day retention based on 600 ton per day production and 400 ton per day bleaching operation). These two systems, then, accounted for an 86 per cent removal of the total BOD and suspended solids load (Table V).

During the lagoon filling period (Apr. 1 to May 23) no wastes were discharged to the stream. This period coincided with the spring herring run —an important consideration in the waste disposal problem.

It is believed the over-all efficiencies may be increased in future operation by further dilution of the pollution load from the mill and by better physical arrangements in the lagoon areas.

Soil Effects

All of the soil in the irrigated area may be classified as sands of the Norfolk type. The permeability of such soil is very high, handling from 2 to 3 in. of applied water every 12 hr.

Preliminary tests made before irrigation began showed the soil to have a pH ranging from 5.6 to 6.9. The calcium, magnesium, and organic content was low. Phosphoric acid content was quite high and potash content ranged from low to medium.

The use of pulp mill effluent for one complete season increased the pH of the soil to a range of 5.9 to 7.2. Tests indicate there has been very little change in the organic matter, and no noticeable increase in the total mineral content of the soil.

Crop Yields

The crops grown on the irrigated area included corn, peanuts, soybeans, and vegetables such as tomatoes, sweet corn, and melons.

On a 5-acre irrigated plot the corn yield averaged 135 bu per acre, the highest yield in Isle of Wight County. On surrounding area, not irrigated, the corn yield averaged 15 to 80 bu per acre, depending on the location of the plot.

For the 5-yr period immediately prior to irrigation, the peanut yield averaged 1,550 lb per acre. After ir-

TABLE V.—Treatment Results

Month (1957)	Per Cent Removal		
	BOD	Suspended Solids	Total Solids
Apr.	All effluent withheld from stream		
May	All effluent withheld from stream		
June	85	74	19
July	89	96	42
Aug.	89	93	33
Sept.	88	89	27
Oct.	85	88	29
Nov.	78	77	16
Avg.	86	86	28

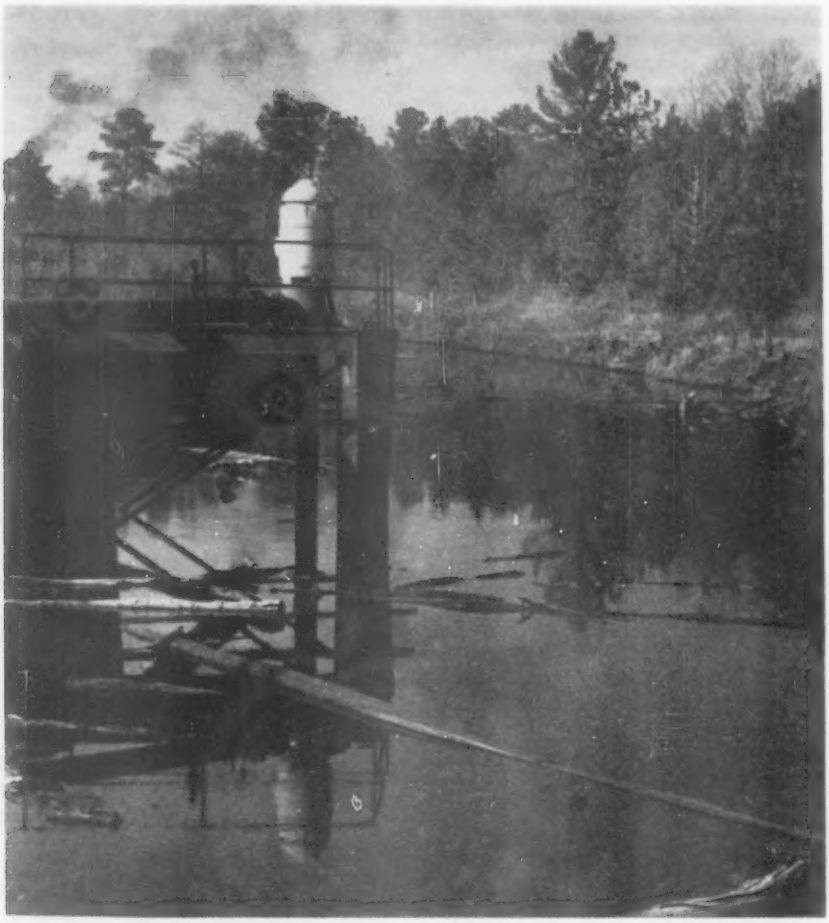

FIGURE 2.—Spray irrigation pump located at end of strong-waste lagoon.

rigation, the yield increased to more than 2,000 lb per acre.

The market grading of these crops ranged from good to excellent. The quality of the vegetables raised was unusually good.

Future Plans

Because of the pH rise in the soil, future fertilizer recommendations will consist primarily of acid-forming materials. Granulated 5-10-10 or 10-20-20 will be used. Side dressings will consist of ammonium sulfate and anhydrous ammonia. Calcium will be supplemented with gypsum, or land plaster, as it is commonly called. It is felt this procedure should be effective in controlling soil pH.

A goal of 250 bu of corn and 2,000 to 2,500 lb of peanuts per acre is planned. At the suggestion of experiment station agronomists new crops will be added to study changes in appearance or quality which may take place. One such experiment will be concerned with

FIGURE 3.—Spray irrigation system in operation in wooded area.

the production of deep-rooted crops, such as alfalfa.

Some fifty acres of woodlands are being sprayed, receiving more water than the open fields (Figs. 2 and 3). To date no noticeable harm has resulted from this practice. However, growth rings will be checked every three years to determine if changes are taking place.

Inasmuch as this approach has been based on a maximum, rather than a minimum, amount of supplemental irrigation some ponding problems have arisen. Amounts of lagoon effluent sprayed varied from 77.2 to 125.9 in. per acre during the 1957 growing season. A series of open ditches designed to drain back into the retention pond will be used to correct this situation. There has been no appreciable erosion.

Cost of Spray Irrigation System

It is difficult to translate land costs from one area to another. The tract of approximately 100 acres acquired

for spray irrigation purposes at Franklin is adjacent to the mill and contained two residences. The cost of acquisition was roughly $25,000.

The investment required in the actual physical layout of the spray irrigation area can be broken down as follows:

Pump, motor, and service transmission line	$ 7,000
Pipe, valves and fittings	25,000
Spray nozzles	6,500
Labor (installation of system)	10,000
Total	$48,500

The total land and installation costs amounted to about $75,000. This figure does not include the cost of the holding lagoon, however.

A daily operating cost of $25 has been assigned to the project to cover power, pump maintenance, and general inspection costs.

Conclusions

From experience to date the following conclusions are drawn:

1. Spray irrigation procedures provide a means for disposing of a considerable portion of kraft mill wastes.

2. Odor problems are not greatly intensified by this procedure.

3. The Franklin system has proved practical from the agricultural standpoint.

WATER POLLUTION ADVISORY BOARD MEETS

The fourth meeting of the Water Pollution Advisory Board was held in Washington, D. C., in May 1958. The Board, under the terms of the Federal Water Pollution Control Act, reviews the policy and program of the Public Health Service and makes recommendations. At the May meeting four resolutions were passed.

Resolution No. 1 commended the PHS for its administration of P.L. 660 and pointed out that continued leadership is necessary if the Federal Government is to discharge its responsibility in the research, technical assistance, and consultative phases of water pollution control.

Resolution No. 2 recommended that, if recession-prompted public works legislation is enacted, waste disposal activities should be vested in the PHS to provide an integrated program and avoid duplication.

Resolution No. 3 urged that the PHS recommend favorable consideration by the Congress of a rapid tax amortization program (five-year) for industrial waste treatment facilities.

Resolution No. 4 concurred in a resolution adopted by the AWWA Board of Directors requesting the PHS to expand virus research and epidemiological studies in the water phase of the environment.

TEXTILE WASTE PROBLEMS *

By Robert S. Ingols

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The biological treatment of textile wastes implies that the conditions in the waste are such that a balanced group of organisms can develop in treatment devices or units. While a treatment plant may vary in its design, its basic purpose is to reduce the potential damage to the quality of streams by treatment before discharge.

Waste Sources

There are many sources of wastes in a textile plant. Many processes have several steps to them, and each step may contribute a particular type of waste material to the total wastes. Among these processes are (a) the addition of sizing to the yarns before weaving; (b) the kiering of fibers which may be used in nonwoven textiles; (c) the desizing of the cloth after weaving in order to prepare it for bleaching, mercerizing, or dyeing; (d) the solutions and washes from the mercerizing and bleaching operations; and (e) the wastes from the dyeing of the various fibers and cloth.

When cotton is colored the dye wastes are highly alkaline and cause high levels of color in the water. From the printing of cotton, the waste contains oily dyes in specks that float as a scum on the surface of the water. In contrast, most wool-dye wastes are strongly acid. The wastes from dyeing the synthetic fibers are mixed with the dyes from coloring natural fibers.

Another waste pertinent to tufted fabrics results from the use of large amounts of synthetic detergents. Where hard water is encountered the extensive laundering required is responsible for these detergents.

Waste Components

Amenable to Treatment

Before the problem of biological treatment can be understood it is necessary to review the nature of the components in the textile wastes which affect biological treatment. One of the most important single factors in textile wastes is the starch from sizing with its high oxygen demand. In treatment, the proper flora must be developed for breaking down the starch. After this is accomplished the utilization of the sugar for energy by the biological treatment device can be considered as an effective waste treatment procedure.

The fibers from textiles are also important in the waste because of their tendency to settle in a stream and create sludge banks. Thus, there is the need for removal and/or destruction of these fibers from such materials as wool and cotton. It is possible that the natural fibers can be destroyed in the digestion process. The synthetic fibers, however, are much more difficult to break down and only further experimentation will show how readily the synthetic textiles are available as food for biological treatment processes.

Where dyeing is practiced, the color in the textile wastes must be considered because of its offensive nature in a

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stream. The dyes are not normal food to the living organisms; therefore, they are not removed readily by most biological treatment devices. Under anaerobic conditions, such as are obtained in long-detention, deep lagoons, the mixture of dyes becomes colorless or grayish and may be broken down to a certain extent. In the absence of a lagoon, however, a large number of the dyes that are received on a trickling filter pass on through the process and become part of the effluent. Therefore, the effectiveness of biological treatment must be evaluated with caution in regard to the treatment of textile wastes because of the persistence of the dyes. Some sulfur dyes require sodium sulfide for their effective use. Sodium sulfide creates a distinct problem in the receiving stream because hydrogen sulfide is eventually formed. Therefore, it is desirable to remove the sulfide ion in a biological treatment process.

Difficult Factors

The previous factors are those which are amenable to biological treatment. However, included with the wastes are other materials which are either inhibitory or which create a great deal of difficulty in developing the necessary organisms for biological growth. Among the factors causing the most difficulty is the high pH from the bleaching and mercerizing operations. High temperature is also a problem. Temperatures of 45° to 50°C have been observed in the wastes from large bleaching operations. This is a problem because most aerobic biological treatment devices do not operate properly above 37°C.

Hydrogen sulfide was mentioned as a factor that can be handled by biological treatment devices but it is also a fact that hydrogen sulfide can be quite toxic to biological treatment under certain conditions. An excessive concentration of the sulfide ion will markedly inhibit anaerobic sludge digestion whether it is present from sodium sulfide or from sodium sulfate by reduction in the digester. Thus, the hydrogen sulfide must be considered, both as a factor to be removed by biological treatment and as one which can be a possible deterrent to biological treatment.

The use of mildew depressants is a newer factor in textile wastes. The role of these depressants in waste treatment has not been studied. Where mildew has been a problem in the preservation or storage of cloth, a depressant that can be mixed with the starch solution (size) affords the textile mill a highly desirable method for controlling degeneration of the cloth. It has been observed that slime does not grow in air-wash systems where these mildew depressants are mixed with the size, while slime does develop in air-wash systems in plants not using mildew depressants. It is possible, therefore, that these fungicides will have a very definite effect on the problem of treating the wastes because biological treatment makes use of the same organisms which would have a tendency to break down the cloth.

Chromates are other chemicals used in the dyeing after treatments with certain dyestuffs. Where chromates are present in the biological treatment process, it is possible that their toxicity to biological growth will be a considerable problem. Fortunately, chromates are not generally used in concentrations responsible for major difficulty.

The fibers, especially of cotton, have definite nutrient deficiencies in respect to utilization in the complex biological treatment systems. These nutrients include calcium, potassium, sulfur, and phosphorus. These deficiencies will have effects on the organisms attempting to utilize them, and must, therefore, be considered in the attempt to set up an adequate biological treatment.

Synthetic detergents can also create difficulties in the treatment of textile wastes. Thus, it has been found in at least one sewage treatment plant * that synthetic detergents can occur in sufficient concentration to disperse completely the suspended material normally received at the sewage plant and, thereby, impose approximately a 50 per cent greater BOD load on the aerobic treatment process than would be anticipated from an analysis of the raw waste and from experiences with normal domestic sewage. It has also been reported by Roberts (1) concerning the treatment of combined sewage and textile wastes that synthetic detergents reduce the effectiveness of the biological treatment in the aerobic removal of BOD from sewage.

In the bleaching of cotton, either as cloth or for nonwoven textiles, chlorine or hydrogen peroxide is commonly used to improve the quality of the cellulose. The hydrogen peroxide wastes can have very little effect on biological treatment, but chlorine can persist in the sewer system to the influent end of a combined treatment unit and cause considerable damage to metal structures and if present can inhibit biological treatment. The by-products of the chlorine reactions on organic matter may also persist to cause some difficulty in biological treatment processes even in the absence of any detectable chlorine residual.

Large quantities of salt are sometimes used in dyeing. Chloride ion concentrations of 2,000 to 3,000 mg/l have been observed although sodium sulfate may be employed causing more difficulty in detection. Lawton and Eggert (2) have indicated that there should be very little biological effect exerted by these salt concentrations, but the maintenance of metallic structures with high salt concentrations in the presence of chlorine is doubly difficult.

* Dalton, Ga.

Solutions to the Problem

Combined Treatment

The complex nature of wastes from textile mills makes it necessary to explore a number of possibilities in order to minimize the organic load on a receiving stream.

Where there is the possibility of treating the textile wastes in combination with domestic sewage, there has been considerable success with the technical aspects. The domestic sewage provides excellent seed, good buffer capacity, and mineral nutrients. Thus, a threefold or fourfold dilution provides a corrective for the high alkalinity of cotton bleaching wastes. This procedure is not uncommon in actual use. Biological treatment is also satisfactory when woolen wastes are mixed with sewage. An example of this is at Cedartown, Georgia. It should be pointed out, however, that there must be cooperation between the operating personnel of the textile mill and the operators of the combined sewage-industrial wastes treatment plant. For instance, the contents of a digester at one of these combined plants was observed to have a pH of 2.5. It was learned after inquiry that two tanks used for storing concentrated sulfuric acid had been emptied after a given period of time because the mill was shut down and the tanks had to be cleaned in order to remove the accumulated rust in the bottom third of the tanks. This situation simply showed a lack of understanding by the mill operators of acid effects on biological treatment. Apparently, the acid remained sufficiently concentrated so that it accumulated in the sludge and was pumped to the digester. Discharge of the acid at a uniformly low rate to afford sufficient dilution would have eased the load on the sewage treatment plant. Thus, it can be seen that with combined treatment of textile waste and domestic sewage an important re-

quirement is voluntary cooperation between the mill and the treatment plant.

However, not all textile plants are located sufficiently near a large city to permit the discharge of their wastes into a sewage treatment plant without some special design considerations. Before treatment of textile wastes became a problem, some of the textile plants felt that the tax situation would be far better if they located their plants just outside the incorporated cities. Therefore, many plants were located too far from city limits to make it practical to deliver the waste to the city sewer system. As a result, some consideration must be given to the problem of treating the textile wastes alone.

Lagoons

Where the temperature of the wastes is high, it is obvious that some means must be provided for heat dissipation. One means of handling these wastes is a large lagoon where heat dissipation, evaporation, and seepage can take place. Lagoons provide a place where partial stabilization of the wastes occurs. Lowering of high pH, typical of many textile wastes, is accomplished in lagoons. Free chlorine will generally be dissipated, and chromates will be reduced, while the chromic hydroxide will accumulate in the sludge at the bottom of the lagoon. These changes are a distinct advantage to the subsequent treatment units. However, lagoons are not necessarily desirable in a location near human habitation since hydrogen sulfide emission is a serious factor. One example of the source of hydrogen sulfide is in waste from indigo blue dyeing, which has a high content of sulfur dioxide.

Where a lagoon is used, it is necessary to provide a means for removing accumulated sludge and scum. Where lagoons are followed by further treatment, the design should provide for an overflow as free as possible from solids. It is possible that a lagoon can be designed to provide the only treatment for textile waste. One of the chief design considerations is the depth of the lagoon. If the lagoon is deep the surface of the ground required will be small but the surface area of liquid through which oxygen may be absorbed will also be small and, therefore, the effectiveness of the treatment of the waste will be limited. Further, as the lagoon depth increases the length of time it remains anaerobic lengthens. This means that objectionable odors such as hydrogen sulfide will persist.

Trickling Filters

When a lagoon discharges onto a trickling filter, hydrogen sulfide is in evidence. Under these loading conditions it has been observed that the filter growth tends to sluff and that a filter might appear completely free of growth following a period of dosing with high sulfide liquor. In this connection it is possible that zinc or sulfur dioxide was present from the mill.

Except for the high hydrogen sulfide content of a lagooned waste, the lagoon discharges can be treated on a trickling filter at reasonable loadings. The degree of effectiveness of the filter is approximately one-half that of the normal sewage treatment load, but this correlation will depend upon the particular waste components. If the synthetic detergent content is high, then the indications are that the effectiveness of treatment may be a great deal less than when the synthetic detergent content is low. When designing a trickling filter installation for textile waste it is found that the BOD concentration, in combination with high volume, requires large filter areas. Thus, where a fairly high degree of treatment is desired it is almost essential that some recirculation be provided.

During the winter, if the temperature of the waste drops to 15°C toxicity factors begin to play a larger role in the problem of effective operation of a trickling filter. At low tem-

peratures, observations made during late April and May indicate that it may be impossible to obtain adequate treatment from a trickling filter during periods of low temperature. Thus, the problem of designing a treatment plant increases with imposed limiting factors. It then appears desirable to provide temperature adjustment at times.

Activated Sludge

Activated sludge has been considered for the treatment of textile wastes. McKinney (3) and McKinney *et al.* (4) have demonstrated in a pilot plant that activated sludge can be modified so that it can function for the treatment of textile wastes. With domestic sewage, the sludge is kept in the final settling tank for some time; in modified design by McKinney and coworkers the sludge from the clarifier returns directly and rapidly into the aerator. This rapid return of the sludge requires the development of a wastes treatment unit where the sludge is continuously recirculated back from the final settling compartment into the aeration device. It is also necessary to carry a concentration of sludge floc approximately twenty times as high as that normal for domestic sewage. This high floc concentration permits the plant to accept large variations in the waste load with minimum effect on the floc quality. The high sludge concentration, however, demands that there be a high capacity air supply to maintain aerobic conditions with 20,000 mg/l floc. The aeration period required for stabilization of the bleachery wastes will be longer as the ratio of textile wastes to sewage increases.

However, a high degree of attention is advised for the operation of activated sludge units to handle textile wastes.

Summary

Textile mill wastes contain a number of components which cause rapid degradation of receiving rivers through biological agencies in the river. However, some mill wastes also include one or more factors which retard or prevent immediate biological action unless there is appreciable dilution, especially at low temperatures. Starch, textile fibers, sulfides, and dyes are components of the wastes which should be reduced by biological treatment. High pH values, high salt concentrations, mildew depressants, chromates, bleach solutions, and synthetic detergents are components which may interfere with biological treatment.

With careful design, it is possible to provide treatment of textile wastes by lagooning, trickling filters, or activated sludge. However, there are advantages and limitations to each method.

References

1. Roberts, F. W., "The Removal of Anionic Syndets by Biological Purification Processes." *Water & Waste Treat. Jour.* (Brit.), **6**, 302 (1957).
2. Lawton, G. W., and Eggert, C. V., "Effect of High Sodium Chloride Concentration on Trickling Filter Slimes." THIS JOURNAL, **29**, 11, 1228 (Nov. 1957).
3. McKinney, R. E., "Activity of Microorganisms in Organic Waste Disposal. II. Aerobic Processes." *Applied Microbiol.*, **5**, 167 (1957).
4. McKinney, R. E., Symons, J. M., Shifrin, W. G., and Vezina, M., "Design and Operation of a Complete Mixing Activated Sludge System." THIS JOURNAL, **30**, 3, 287 (Mar. 1958).

Stream Pollution

SLIME INFESTATION—LITERATURE REVIEW*

I. *SPHAEROTILUS*

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The term "slime infestation" is an attempt to describe the phenomenon of a certain community of organisms which appears under varying ecological conditions. It is synonomous with the term "abwasser-pilz" of Tiegs (41), and its English equivalent, "sewage-fungus" of Butcher (5). These terms have their limitations in that they use words in a general sense which have specific biological meanings. Butcher was aware of the deficiency of his term, for he pointed out that the community included not only fungi, but also four species of schizomycetes and two stalked protozoa. He went on to define it as "the community of polysaprobic organisms with a fungus-like growth." The one word in this definition to which exception might be taken is polysaprobic. This implies conditions of gross pollution, while this community may exist in rivers with otherwise no evidence of pollution. The term "slime-infestation" has its merits in that it implies an undesirability or offensiveness. The verb "infest" is defined as "to trouble greatly by numbers or by frequency of presence," so that the term "infestation" is a good choice. However, from the word "slime" it might be erroneously concluded that the slime-fungi, the myxomycetes, or the slime-bacteria, the myxobacteriales are involved in this phenomenon. Wuhrmann (49) uses the terms "heterotrophic biocoenosis" to distinguish this community of living organisms requiring pre-formed organic matter from the "autotrophic-biocoenosis"—consisting mainly of inoffensive and often desirable algae.

Problem

Before proceeding to a detailed consideration of the slime community, it might be relevant to describe in very general terms its appearance, the conditions under which it develops, and its offensive effects.

This growth has been simulated to white or discolored sheep's wool and to cotton-wool; and has been described as floating-crests, or plumes which form massive growths either attached to the river bed or floating and attached to a variety of surfaces. It never appears visibly green; so that here a distinction from an algal bloom is made.

The typical manifestation occurs in a river or stream below a source of pollution—either from domestic sewage or from industrial waste; its occurrence may be seasonal and sudden.

At its initial appearance it is offensive aesthetically—depriving the water course of its natural beauty and allied amenities. It becomes a great nuisance to fishermen, fouling the lines, clogging the nets, and even rendering the fish undesirable by their appear-

* Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University.

ance. Its secondary effects may be even more serious—the growths become detached and settle either at or near the original location or are carried downstream to areas where the flow velocity allows settling. Here sludge banks are formed which give rise to anaerobic conditions with subsequent offensive effects. This may occur many miles away from the source of pollution which initiated it.

Methods of Study

Field Work

Successful preliminary identification of the causative organism always includes direct microscopic examination of field samples.

The techniques described and used by Harvey (16) and Cooke (8)(9) for the evaluation of the role of fungi in polluted waters and sewage are not applicable to the study of slime infestations. The methods described by these workers involve inoculation of water samples into selective media. These media include a high proportion of some protein material (0.5 per cent Soytone or Phytone) and an antibiotic (e.g., aureomycin) for suppression of undesirable bacteria. Of the species named by Cooke (9) as occurring both in the free water and associated sediments of the sewage polluted Lytle Creek, none has been identified by other workers as being dominant in slime infestations.

In a discussion on the role of aquatic fungi in hydrobiology, Weston (45) emphasizes the distinction that "should be drawn between the occurrence of the aquatic fungi in a passive, dormant, resistant condition, and their occurrence in an active, functioning state." The methods described by Harvey and Cooke do not distinguish between these two groups because their media are markedly dissimilar in nutrient content from those found under natural conditions.

Many workers in Europe have been preoccupied with the secondary pollutional effects of such infestations. The large masses of growths detached from their original growth locations may form objectionable sludge banks behind impoundments many miles away from their original source. Research workers in Germany, therefore, have attempted to obtain quantitative data on the weights of growths occurring in particular rivers.

Two methods have been employed. The earlier one used by Potonie and Wundsch (32) utilized a net mounted on a frame. The mesh of the net was in the order of 2.5 mm. This was immersed across the stream and the floating fungus caught and weighed. A later refinement of this method by Demoll and Liebmann (13) involves pumping the water from a definite depth, the growth being caught in an apparatus similar to a plankton sampler and subsequently weighing the sample. Both dry and wet weights have been employed.

By such methods, Demoll and Liebmann (13) quote Bandt as giving the following classification for the fungus quantity in a stream as a basis for comparison to other water-courses:

Floating Fungus (strength)	Fungus Quantity (g/cu m)
Weak	2
Medium	2–4
Strong	4–6
Very strong	6

These techniques may give the over-all picture of occurrence of the growth in a particular stretch of water, but certain inherent limitations of the method should be indicated:

1. Collection either with a net or by pumping cannot give an accurate measurement of the amount of fungus. Such fragile growths are easily detached—especially in sampling from the lower depths.

2. It is well known that the growths can occlude much debris of all types,

and their inclusion will add another positive error.

3. It is impossible to distinguish between living and dead material. The weight of the latter will be less than that of the original growth because of its decomposition.

4. Sampling at one particular time gives the total growth over an unspecified period of time: in other words, it is the "standing-crop." Because of this, it may not be related to the amount of pollution without accurate information upon the total amount of oxidizable material available and this would require full details of the organic load, the flow, and the time of development.

Butcher and his co-workers (6) successfully used the slide technique of Henrici to obtain information upon the sequence, amount, and type of growths occurring under certain conditions.

An under-water photographic method was used by Liebmann (22) to obtain information upon the succession of ciliates occurring upon the flocs of *Sphaerotilus*.

Laboratory Work

Because of the many variables to be considered when studying stream conditions, most information upon the nutritional requirements of stream organisms has followed their isolation in pure culture. It is desirable to make the isolation from the actual infestation. In this way, the possibility of physiological variants is minimized, and better application of the laboratory results to field conditions is possible. Details of the isolation procedures will be given in the appropriate sections.

The most valuable method of study, however, is one where stream conditions are simulated. This has been used to advantage by Wuhrmann (49) and Amberg and Elder (2). Wuhrmann adapted the methods of Blochliger and Husmann, using a system of five, parallel concrete channels with a slight slope. Gravel filled the bottom to a depth of 1.5 in., and the feeds (river water with different dilutions of treated and untreated sewage) were maintained at definite flow rates. Observations of the resulting communities of organisms could be correlated with the one variable of the different feed.

Amberg and Elder (2) utilized pyrex tubes (60 in. by 2½ in.) in which a plasterer's lath was suspended for attachment surface. The feed was preheated to the required temperature, and mixtures of river water and sulfite waste liquor were fed into the channel by a multi-feed constant displacement pump. At the end of the experiment, the growths were removed and estimated.

The greater operating difficulties have possibly precluded the use of such constant flow devices to study the development of slime infestations when supplied with specific mixtures of compounds. These experiments are needed to yield information on development in waters of low nutritive value, when large masses of growth often develop.

Constituent Organisms

The organisms constituting slime infestations have been most reliably recorded by workers who have undertaken field sampling and subsequent microscopic examination. Tiegs' (41) early description of the "abwasserpilz" community included the following organisms: *Sphaerotilus natans, Zoogloca ramigera, Beggiatoa alba, Thiothrix nivea, Fusarium aquaeductum, Leptomitus lacteus,* and *Mucor* sp. Butcher's (5) subsequent description of his "sewage-fungus" community also included the fungus *Selenospora* and the protozoan *Carchesium*.

It is important to realize that within any community of organisms, there are one or more members which exert a major influence, because of greater numbers, size, or activities. These are said to be the dominant species. Odum

(30) defines a dominant as "an organism which exerts a major controlling influence on the community," and further states that "removal of the dominant would result in important changes in the community, whereas removal of a non-dominant species would produce much less change." It is therefore necessary to know which organisms are dominant in the community. The two organisms which have been repeatedly described as ecologically dominant are *Sphaerotilus natans* and *Leptomitus lacteus*.* The presence of one does not seem mutually to exclude the other. Liebmann (22) describes *Leptomitus* as appearing on flocs of *Sphaerotilus*. Reports, however, emphasize the presence of one or the other as causing the infestation. The factors affecting the development of these two organisms will be reviewed in detail.

Fusarium aquaeductum has not been reported as causing a slime infestation in the U. S.; it occurs only in waters of low pH. The two filamentous sulfur bacteria, *Beggiatoa alba* and *Thiothrix nivea*, certainly do not form massive growths. They are fragile, delicate organisms, occurring in locations where hydrogen sulfide is available. Liebmann (22) describes them as being present on *Sphaerotilus* flocs after anaerobic decomposition had occurred.

Many other organisms—bacteria, protozoa, and algae—have been reported to occur within the community. Gaufin and Tarzwell (15) in a biological survey of a creek receiving sewage pollution record maximum *Sphaerotilus* at a station where rhizopods and ciliates were at a minimum. Thereafter, the *Sphaerotilus* decreased in amount as the rhizopods and ciliates increased their numbers. They attribute the decrease in *Sphaerotilus* to a reduced food supply and to the voracity of the bacteria-feeding rhizopods associated with them. There is no experimental evidence, however, that any of these accompanying organisms play a significant role in limiting or stimulating the development of the community. They can therefore be regarded as secondary invaders of the initial infestation.

A novel consideration of these accessory organisms was presented by Liebmann (22) who investigated the growth of *Sphaerotilus* infestations in rivers in Germany. He stated that certain attached ciliates could yield information on the age of the floc. The main ciliate occurring on *Sphaerotilus* flocs to a distance of 10 km below the polluting sewage outfall was *Colpidium colpoda*, and was replaced beyond this by *Glaucoma pyriformis*. Naumann (25)(26) reports similar changes in accompanying organisms with decomposition of the floc. It is difficult, however, to see how such observations can be applied to any river at any time; factors other than that of the age of the *Sphaerotilus* could affect the accompanying organisms.

Methods of Isolation

Attempts of early investigators failed because of the difficulty of obtaining preferential growth of *Sphaerotilus* over the contaminating organisms adhering to the mucilaginous sheath.

However, the isolation of *Sphaerotilus* in pure culture has been accomplished and described in detail by many workers (3)(7)(17)(19)(33)(35)(36)(40). In this isolation a floc of the growth is transferred to an agar plate of nutrient medium. After two to three days incubation at 20 to 25°C, filaments of the organism may be seen by the low power of the microscope to have grown away sufficiently from the contaminating bacteria so that they may be transferred into liquid media. Best results are ob-

* Subsequent reference to the generic name of the two organisms refers to these species unless otherwise stated.

tained at this stage by cutting out a small piece of the agar and transferring it into liquid media. Subsequent subcultivation insures purity of the culture.

The success of the method depends on the following factors:

1. The use of a floc of *Sphaerotilus* with the least possible contamination. This is accomplished by (a) enrichment, and/or (b) subsequent thorough washing of the filaments with sterile water.
2. The use of dilute nutrient media, e.g., 0.05 per cent meat extract.
3. The thorough drying of the surface of the medium before inoculation. This prevents the spreading of contaminants.

Morphology

The classic description of the type species, i.e. *Sphaerotilus natans,* is of individual cells united into unbranched filaments and surrounded by a slimy sheath.

Stokes (40) is the only observer who states that young filaments are not differentiated into individual cells, and that cell walls are laid down later. Höhnl (17) observed that the cells were rod-shaped in young cultures and cocci in older cultures.

The 6th Edition of the Bergey Manual gives the diameter of the cells as being 2 to 3 μ, and most observers agree that this dimension of the cell is more definitive than the length. Both Butcher (5) and Stokes (40) state the diameter to be less than this. Differences may be due to differentiation of the cell and surrounding sheath when measuring.

The length of the cells varies with the age of the culture, the source of isolation, and the culture medium. Pringsheim (33) states somewhat arbitrarily that the length is equal to or twice the width. The range in length may be deduced from the following list of observers and described cell lengths:

Observer	Ref. No.	Cell Length (μ)
Butcher	(5)	3–6
Lackey and Wattie	(19)	3–8
Stokes	(40)	2.5–16
Höhnl	(17)	5–11

There is a lack of information on the sheath which unites the cells into filaments. Pringsheim (33) differentiates between a delicate primary sheath and subsequent deposition upon this. The *Leptothrix ochraces* form arises when an inorganic deposit is laid down, whereas in *Sphaerotilus,* mucilage is deposited. Beger and Bringmann (4) consider its taxonomic significance. It is this which confers the sliminess to the organism which is so evident in the locations where an infestation occurs. The width of the sheath is described by Höhnl (17) as being 1 to 2 μ larger than the cells. Stokes (40) affirms that the width of the cells can also be considered to be the width of the sheaths and the filaments. This does not seem possible if one considers the sheath to be formed externally to the cells. The only information on their chemical composition is quoted by Stokes from Linde's work, who stated that the sheaths are soluble in 50 per cent sulfuric acid, 60 per cent potassium hydroxide, or in ammoniacal copper sulfate solution. The sheath is clearly visible on negative staining with nigrosin (33). It may also be lightly stained with Haematoxylin after Schaudinn's fixative (19) or with the Löeffler modification of Giemsa's stain (17).

Apart from a cursory reference by Höhnl (17) to the sheath being well developed in glucose media, there is no information on the optimum conditions for its formation.

Many observers report that the sheath can give a positive Prussian blue test for iron; a fact often referred to as a basis for the inclusion of *Sphaerotilus* in the "iron-bacteria." This is a loose term, generally applied to those organisms possessing mecha-

nisms for oxidation of iron compounds and utilization of the energy for autotrophy.

It is generally agreed that reproduction may occur by fragmentation of the filaments or by formation of motile conidia. Pringsheim (33) observed the conidia to have a single polar flagellum, but other investigators state that they are lophotrichous.

The appearance of freshly isolated *Sphaerotilus* on solid media containing proteinaceous materials is distinctive. The colonies are delicate, irregular in outline, and of a creamy-white to yellow color. The filamentous appearance of the colony becomes apparent on examination with the low power of the microscope. An arrangement of the filaments giving characteristic spiral designs is observed.

Reference by Stokes (40) to the dissociation of the characteristic, rough first isolation colonies, the "R" type, consisting of filaments, to a smooth "S" type, consisting of smooth glistening colonies of single cells, has not been confirmed. Pringsheim (33) observed a similar dissociation in the related organism *Sphaerotilus discophorus*, but he considered this organism to be distinct from *Sphaerotilus natans*. The possible importance of Stokes' observation will be discussed later.

Observers have noted that the forms observed in streams are not readily reproducible under lab conditions in liquid media. Lackey and Wattie (19) note more characteristic forms when the cultures are aerated. With one exception, a delicate, tufty growth described by various workers as "cobwebs" or "cotton-wool" is described from stationary cultures. Stokes (40) differs in describing a coherent, slimy surface-mat or pellicle in liquid media, with some of the growth clinging to the sides and bottom of the flask in the form of a delicate film, or as granules, the liquid medium remaining always clear. Turbidity, he states, indicates contaminants.

Taxonomy

The taxonomy of the family Chlamydobacteriacae of which *Sphaerotilus natans* is a member is far from satisfactory. While most of these considerations are academic where a sudden infestation in a river is concerned, the literature contains information on two important aspects of the problem related to stream pollution.

The first concerns the possible difference in appearance of the organism under different conditions. Butcher (5) divided *Sphaerotilus natans* into varieties based on small differences in sizes of the cells and on the aggregation of the filaments into bundles. He correlated the appearance of these varieties to different physiological conditions, and postulated the step-wise development of different varieties through different zones of pollution. This work was based on field observations of the organism in a number of locations.

Later work (33) (17) conclusively demonstrated that on cultivation, the same organism develops whatever the original source, and it is certain that small differences in the appearance of a *Sphaerotilus* infestation in a stream are not due to inherent differences in the organism concerned, but are correlated with different nutrient conditions. Descriptions of the organism when growing under varying conditions in the laboratory are meager. Apart from a general statement that different forms develop with dilution, there is not sufficient evidence to be able to define more specifically the conditions giving rise to different forms. The second aspect concerns the sudden appearance of the organism in a stream; field workers stress the rapid development of *Sphaerotilus* into infestation proportions after the entry of pollution. It seems necessary to postulate the continued presence in the river of a form which can give rise to this massive growth.

Naumann (28) early investigated the possibility of *Cladothrix dichotoma* being transformed into *Sphaerotilus natans* under certain conditions. These organisms are similar, except that *Cladothrix dichotoma* exhibits regular dichotomous branching of the filaments, and does not have the slimy sheath of *Sphaerotilus*. The whole question of the interconvertibility of the Chlamydobacteriaceae was studied by Pringsheim (33). He showed that *Sphaerotilus natans, Cladothrix dichotoma,* and the ecologically distinct *Leptothrix ochracea* could give rise to similar cultures by appropriate treatments. This has been confirmed by later workers, notably Höhnl (17) and it seems definite that *Cladothrix dichotoma* can give rise to *Sphaerotilus natans* under certain conditions. Laboratory cultivation and field observations indicate that *Cladothrix* is formed in waters of lower nutritive value. The only quantitative determination was carried out by Bahr (3), who noted that the *Sphaerotilus* appeared at a concentration of meat extract of 0.5 per cent, but *Cladothrix* appeared at 0 05 per cent.

Bahr also reports the sequence of the development of *Sphaerotilus* from a culture of *Cladothrix*. He noted the following stages when additional amino acid (0.3 per cent asparagin) was added to meat extract.

1. The aggregation of *Cladothrix* filaments and a concurrent "slime buildup."
2. The development of single motile cells within this aggregation and their subsequent release.
3. The growth of these single cells into the typical *Sphaerotilus* form.

Although no field work has been reported to confirm this hypothesis, it is interesting to note his postulation of a "slime buildup" prior to typical *Sphaerotilus development*. It seems to indicate that specific conditions favoring excessive development of the mucilaginous layer must be present before an infestation can occur.

Butcher *et al.* (6) applied the Henrici technique to the study of the phenomenon by immersing glass slides in the river Lark during a beet-sugar season. After 24 hr, the slide showed filaments containing two or more cells; after 48 hr, the filaments had lengthened to contain 2 to 10 cells, while after 72 hr, they contained 10 to 30 cells. This points to the fact that development initially involves a gradual filament-length increase from smaller components, which may even be single cells.

Field observations show that the long, filamentous forms of *Sphaerotilus* are often absent from highly polluted areas. The organism also fails to develop typically in rich laboratory media. Stokes' observation on the dissociation of his culture into individual cells when transferred into rich media may indicate an explanation for this phenomenon. If the rupture of the filaments into individual cells is a response to a high concentration of food, then the formation of filaments could be a response to low concentration of food.

In his studies on slime formation when various surfaces were immersed in sewage, Crosby (11) found an increase in slime growth with dilution. Although he did not identify *Sphaerotilus* in large amounts at any of his stations, he found a decrease in BOD with an increase in slime accumulation. This observation indicates the possibility that minimal nutrient conditions may cause the formation of viscous or gelatinous films.

There is evidence, therefore, that *Sphaerotilus natans* may arise in a river from the *Cladothrix* form, either directly or from motile reproductive cells. The conditions conducive to such a change may be associated with the production of the mucilaginous sheath so characteristic of massive growths of the organism.

Nutritional Requirements—Carbon Compounds

The classic descriptions of the four zones of decomposition below the entry of sewage into a stream always include *Sphaerotilus* as a member of the polysaprobic zone.

It is certain that domestic sewage contains the necessary carbon compounds for the growth of the organism. Although there are many reliable reports of the occurrence of the organism in a stream receiving domestic sewage, little information is available upon its growth in sewers. Wuhrmann (46) asserts that the organism does not grow in undiluted sewage. De Martini (12) reports the organism in sewers carrying very dilute sewage, while Agersborg and Hatfield (1) note that it is present in raw sewage, Imhoff tanks, and aeration tanks. In descriptions of the biota of trickling filters, *Sphaerotilus* is not considered to be a dominant organism. Large numbers of *Sphaerotilus* were, however, reported on the surface and underside of upper rocks of a trickling filter at the sewage treatment plant at South St. Paul, Minn. This is a plant which handles a large volume of wastes from meat packing plants. A wealth of data is available on its occurrence in activated sludge units. Its presence is associated with the phenomenon of bulking and the presence of excess high energy food materials.

The appearance of *Sphaerotilus* in a stream as the dominant organism has repeatedly been correlated with the entry of industrial wastes. Based on observations on rivers in Yorkshire, England, Butcher (5) lists these as being effluents from the following industries: beet sugar, paper, rayon (viscose process), glue, and flour mills.

Other observers have noted other stimulants to its heavy growth: textile bleach, by-product coke, dairy wastes, and spent sulfite liquors.

In efforts to obtain more specific information on the carbon compounds which promote the growth of the organism, workers with pure cultures have progressed from the use of ill-defined media, such as meat extracts and protein hydrolysates, to the use of media incorporating specific organic compounds. In such experiments a basal medium containing the known necessary nutrients (minerals and nitrogen) is supplemented with the compound to be investigated, and growth is measured after a certain incubation period. The results are assembled in Table I. The concentrations are expressed in ppm to permit comparison.

Of the carbohydrates, it appears certain that glucose, maltose, and sucrose can serve as carbon sources for *Sphaerotilus*, although both Lackey and Wattie (19), and Smit (39) show that lactose is also available. This result is not confirmed by Stokes (40). Höhnl (17) reports good utilization of mannose and moderate growth with xylose, ribose, galactose, fructose, and saccharose. Other workers confirmed these results in the cases of galactose and saccharose. Arabinose was found unavailable by Stokes (40) and Smit (39), but Höhnl (17) noted slight growth; cellobiose and rhamnose do not result in growth. Smit's work confirms Stokes' observation that mannitol is used.

Among organic acids, acetic and lactic acids are readily available and Stokes also reported the utilization of succinic, fumaric, pyruvic, and butyric acids. Höhnl could not confirm this reported utilization of succinic and fumaric acids, but in addition found good utilization of malic acid and poor results with pyro-racemic, tartaric, oxalic, and citric acids. Neither benzoic nor propionic acids were capable of being used.

Of the alcohols, Stokes reports ethanol and butanol as being available, but methanol and propanol unavailable. Höhnl does not confirm the result with ethanol. Both workers found

TABLE I.—Utilization of Carbon Compounds by *Sphaerotilus*

Compound Tested	Stokes (40)*		Höhnl (17)†		Lackey and Wattie (19)‡		Smith (39)§	
	Conc. (ppm)	Result of Growth	Conc. (ppm)	Result of Growth	Conc. (1,000 ppm)	Result of Growth	Conc. (ppm)	Result of Growth
Arabinose	2,500	None	2–10,000	Slight	—	—	—	—
Xylose	2,500	None	2–10,000	Moderate	—	—	—	—
Ribose	—	—	2–10,000	Moderate	—	—	—	—
Glucose	2,500	Good	2–10,000	Good	1–10	Good	—	—
	10,000	Delay	—	—	—	—	—	—
Mannose	—	—	—	—	—	—	—	—
Galactose	2,500	Good	2–10,000	Good	1–10	Good	—	—
Fructose	—	—	2–10,000	Moderate	—	—	—	—
Levulose	—	—	2–10,000	Moderate	1–10	Good	—	—
Salicin	—	—	—	—	—	—	—	—
Saccharose	—	—	2–10,000	Moderate	—	—	—	—
Maltose	2,500	Good	2–10,000	Good	1–10	Good	50–10,000	Good
Lactose	—	—	—	—	—	—	50–10,000	Good
Cellobiose	—	—	—	—	—	—	—	—
Sucrose	2,500	Good	—	—	1–10	Good	50–1,000	Good
Rhamnose	—	—	2–10,000	—	—	—	—	—
Sorbitol	2,500	Good	—	—	—	—	—	—
Mannitol	2,500	Good	—	—	—	—	—	Good
Succinic acid	2,500	Good	1,180	Moderate	—	—	—	—
Fumaric acid	2,500	Good	1,160	Moderate	—	—	—	—
Butyric acid	1,000	Good	—	—	—	—	—	—
(as Na salt)	2,500	Toxic	—	—	—	—	—	—
Lactic acid	2,500	Good	900	Good	—	—	—	—
Pyruvic acid	2,500	Good	—	—	—	—	—	—
Acetic acid	1,000	Good	—	—	—	—	—	—
(as Na salt)	2,500	Toxic	600	Good	—	—	—	—
Propionic acid	1,000	—	740	—	—	—	—	—
Malic acid	—	—	1,340	Good	—	—	—	—
Pyro-racemic	—	—	1,680	—	—	—	—	—
Tartaric acid	—	—	1,500	—	—	—	—	—
Oxalic acid	—	—	1,260	—	—	—	—	—
Citric acid	—	—	1,920	—	—	—	—	—
Benzoic acid	1,000	—	—	—	—	—	—	—
Methanol	1,000	—	320	—	—	—	—	—
Ethanol	1,000	Good	460	—	—	—	—	—
Propanol	1,000	—	—	—	—	—	—	—
Butanol	1,000	Good	—	—	—	—	—	—
Glycerol	2,500	Good	920	Good	5–10	—	—	—
Sodium oleate	—	—	—	—	5–10	—	—	—
Sodium stearate	—	—	—	—	5–10	—	—	—
Oleic acid	—	—	—	—	5–10	—	—	—
Stearic acid	—	—	—	—	5–10	—	—	—

* Nine strains isolated from waters. Mineral solution plus 0.05 per cent casein hydrolysate used as basal medium and nitrogen source.

† Five strains isolated from ecologically significant populations. Minerals plus 0.02 per cent peptone plus 0.01 per cent KNO_3 used as basal medium and nitrogen source.

‡ Fourteen strains isolated from activated sludge. Sterile raw sewage used as basal medium and nitrogen source.

§ Activated sludge.

good growth with glycerol; their non-agreement with the work of Lackey and Wattie (19) is probably due to the latter's use of excessively high concentration and consequent inhibition. On testing a range of fatty acids and associated soaps, Lackey and Wattie found no significant utilization of any.

While these results are valuable in yielding information about the availability of certain compounds as carbon supply for the organism, there are certain inherent limitations in the methods which should be considered when an attempt is made to project the results to actual stream conditions. These are:

1. Since the methods utilize static cultures, a certain compound is necessary to allow growth to be estimated. A non-utilization of a compound under such conditions need not preclude its utilization under the much lower concentrations which would prevail in a stream with its constant flow. The methods cannot differentiate between degrees of inhibition of activity at high concentrations, and total non-utilization.

2. The methods do not differentiate between the capacity of the organism to utilize a certain compound as an energy supply, and its ability to use the carbon material for cell synthesis. For growth to occur on a single compound, that compound must function in both ways. Stokes, for instance, found that although benzoic acid did not result in growth of the organism, it was used in respiration. The possibility should be considered therefore that a compound capable of yielding cell material would result in greater growth if an additional energy supply were present. Such possibilities can only be confirmed by experimental work using mixtures of carbon compounds.

The constant flow experiments of Lincoln and Foster (23) confirm some of the pure-culture results. Using experimental troughs they utilized a continuous flow of river water with different concentrations of spent sulfite digester liquors. A concentration of 50 ppm was necessary to give any visible growth after 7 days; above this value, the amount of growth was proportional to the concentration. Subsequently, by using fractions of the liquor, they demonstrated that the growth stimulants lay, not in the solutions of inorganic salts (sulfites and bisulfites) or in the calcium lignosulfonate fraction, but in the fraction containing sugars and their derivatives (the pentoses, hexoses, alcohols, and aldehydes). This was confirmed by Liebmann (20).

It is impossible to assess accurately the capacity of a stream to give rise to an infestation of *Sphaerotilus* by reference to the values of BOD, COD, oxygen consumed from permanganate, or any other criterion of total organic matter. This is emphasized by recent observations of Amberg and Elder (2) that prolific slime growth resulted with continuous dosages of spent-sulfite-calcium base liquor equivalent to a BOD loading of 1.4 ppm. Without knowledge of the contributing BOD compounds, such a value would normally indicate unpolluted conditions.

Wuhrmann (49) points out that it is the constituent compounds causing the BOD and not the total BOD value which is critical in this respect. He conducted channel tests to estimate the effect on a receiving stream of differently treated domestic sewage. Continuous addition of 11 ppm of BOD in settled sewage resulted in a heavy development of *Sphaerotilus*, while addition of the same amount of BOD from sewage treated by the activated sludge process gave no such development. Similar results were obtained with values of oxygen consumed from permanganate and from values of organic nitrogen. When 1 ppm of organic nitrogen was contributed by the settled sewage, it resulted in heavy growths of *Sphaerotilus*, but 1 ppm of organic nitrogen from activated sludge treatments did not give the growth. He concludes that such tests as the "BOD, organic nitrogen, organic carbon, and oxygen consumed, are analytical procedures which combine large groups of substances having extremely

diversified chemical constituents," but give no indication of "their physiological value to troublesome organisms such as *Sphaerotilus.*"

There is a little evidence that *Sphaerotilus* has a high efficiency in conversion of carbon compounds into cellular material. Stokes reports on the basis of oxygen uptake of the organism in media containing specific carbon compounds that the organism has a high oxidative assimilation, but he fails to differentiate between the amount of substrate oxidized for energy purposes and that assimilated into protoplasm. Höhnl calculated the ratio of cell material formed to substrate glucose utilized to be 0.19 to a value almost twice that normally found in bacterial metabolism. Further information on this aspect of the nutrition of the organism would be valuable in explaining the massive occurrence of the organism with low pollutional loads.

Nutritional Requirements—Nitrogen Sources

Substances capable of serving as nitrogen sources for *Sphaerotilus* have been intensively studied by many workers, but present knowledge is still far from satisfactory. Early workers agreed that proteins or their hydrolysates were necessary for most luxurious growth, but observations that growths occurred in locations where such concentrations of proteinaceous material were absent led later workers to more precise investigations.

Inorganic Nitrogen

There is general agreement that the luxurious growths similar to those found under stream conditions cannot be reproduced in the laboratory with inorganic sources of nitrogen. Table II assembles the relevant data.

Zikes (50) reported that *Sphaerotilus* could not use inorganic forms of nitrogen, while Cataldi (7) confirms Lackey and Wattie's observation that there was fair growth with ammonium and nitrate salts, but no growth in nitrite. The observations of Stokes (40) differ from those of all other workers. He reports the interesting fact that the degree of availability of the inorganic nitrogen compounds is dependent upon the carbon supply. He obtained poor growth with both nitrate and ammonium salts when glu-

TABLE II.—Utilization of Inorganic Nitrogen Compounds by *Sphaerotilus*

Nitrogen Source	Stokes (40)*			Höhnl (17)†			Lackey and Wattie (19)‡		
	Conc. of N_2 Source (ppm)	Carbon Source	Growth	Conc. of N_2 Source (ppm)	Glucose as Carbon Source (ppm)	Growth	Conc. of N_2 Source (ppm)	Dextrose as Carbon Source (ppm)	Growth
Ammonium	1,000§	Glucose	None	NH_4Cl:100	1,000	Cells destroyed	Not stated	1,000	None
Ammonium	1,000§	Sucrose	Excellent	NH_4Cl:10	1,000	Cells destroyed	Not stated	1,000	—
Ammonium	1,000§	Glycerol	Excellent	$(NH_4)_2SO_4$:100	1,000	Cells destroyed	Not stated	1,000	—
Ammonium	1,000§	Glycerol	Excellent	$(NH_4)_2SO_4$:10	1,000	Cells destroyed	Not stated	1,000	—
Nitrate	1,000§	Glucose	None	KHO_3:100	1,000	good	$NaNO_3$:112	1,000	Slight
Nitrate	1,000§	Sucrose	Excellent	KHO_3:10	1,000	good	—	1,000	—
Nitrate	1,000§	Glycerol	Excellent	—	1,000	—	—	1,000	—
Nitrate	1,000§	Succinate	Excellent	—	1,000	—	—	1,000	—
Nitrite	—	—	—	$NaNO_2$:100	1,000	Inhibited	—	—	—
Nitrite	—	—	—	$NaNO_2$:10	1,000	—	—	—	—

* Nine strains from water. Mineral base used as basal medium.
† Strains not stated. Mineral base used as basal medium.
‡ Fourteen strains isolated from activated sludge. Mineral base used as basal medium.
§ Salt not stated.

cose was the carbon source, but when sucrose, glycerol, or succinate were substituted, excellent growth resulted. These results need confirmation in view of their practical significance.

Using glucose as the carbon supply, Höhnl (17) found that concentrations down to 10 ppm of ammonium salts resulted in inhibition of growth and cell damage. If Stokes' results have validity, the effect of the ammonium salts is influenced by the carbon source, glucose. It is difficult to accept that such inhibition would be eliminated merely by changing the carbon source. Höhnl's strains are probably physiologically more typical of those found in infestations than those of Stokes. Höhnl isolated his strains from locations where the organism was ecologically dominant, while Stokes used a primary enrichment technique to obtain growths from locations where the organism was not ecologically significant. Further indication that different physiological strains are involved is given by the results on amino-acid utilization.

Höhnl's observation on the inhibitory effect of ammonium salts leads him to infer that the concentration of ammonia may be a limiting factor to *Sphaerotilus* growth in locations heavily polluted with organic material, e.g. in sewers. His experiments were conducted in media without alternative nitrogen sources, where he noted decreased endogenous respiration when ammonium salts were present. This reasoning cannot be applied where the organic pollution is of sewage origin and where there would be available organic sources of nitrogen. Popp and Bahr (31) state also that they do not consider excess ammonia to be a factor limiting the growth of *Sphaerotilus* in the polluted Altenau River.

Organic Nitrogen

There are many references in the literature to the necessity of a supply of amino acids by *Sphaerotilus*. For example, Wuhrmann (48) states that amino acids are necessary in a certain dilution for the appearance of the organism.

Table III assembles the data of pure culture work on amino acid availability.

Asparagine, alanine, and arginine are confirmed as being readily available compounds, but Lackey and Wattie's (19) results do not confirm those of Stokes (40) and Höhnl (17) on the availability of glutamic acid. There is disagreement in the results reported by Stokes and Höhnl on other amino acids. Stokes' results showed that aspartic acid, cystine, tyrosine, tryptophane, proline, and leucine were good sources of nitrogen, while Höhnl. and Lackey and Wattie showed that cystine, leucine, and tyrosine were poorly available. Höhnl reports good growth with methionine and threonine, while Stokes obtained little or no growth with either of these compounds. Other acids which Stokes found to give little or no growth were serine, lysine, iso-leucine, glycine, histidine, and phenylalanine. In their reported experimental details, not all workers denote whether L- or DL-amino acids were used. There is some evidence that other microorganisms are inhibited by D-amino acids. It is possible that the disparity in results of different workers could be explained on this basis.

Various workers have found the following compounds unavailable: acetonitrile, isatin, globulin, urea, acetamide, creatinine, and sarcosine.

Many observers have noted that heavy *Sphaerotilus* growths occur only when domestic sewage is diluted with river water. Wuhrmann (47) reports that the organism will not grow in sterilized conditions in undiluted sewage, although growth occurred when the sewage was diluted twenty-fold. Littman (24) had noted this phenomenon, but obtained growth when

TABLE III.—Utilization of Organic Nitrogen Compounds by *Sphaerotilus*

Compound Tested	Stokes (40)[a]	Höhnl (17)			Lackey and Wattie (19)[a]
		Nitrogen Source Test[b]	Inhibition Test[c]	Carbon Source Test[d]	
Leucine	Excellent[f]	None	Good	None	Slight[f]
Glycine	None	—	—	—	None
Glutamic acid	Good[f]	Good	—	—	None[g]
Aspartic acid	Good[f]	—	—	—	—
Asparagine	Good[f]	Good	—	Excellent	Good[f]
Alanine	Good[h]	Excellent	—	Good	Good
Cystine	Good[f]	None	Good	None	None
Tryptophane	Good[h]	—	Inhibitory	—	—
Tyrosine	Excellent	None	Good	None	None
Arginine	Good[f]	Good	—	Slight	—
Proline	Excellent[f]	—	—	—	—
Serine	None[h]	—	—	—	—
Lysine	None[f]	—	—	—	—
Methionine	None[h]	Good	Good	None	—
Iso-leucine	None[h]	—	—	—	—
Threonine	None[h]	Good	Good	None	—
Histidine	None[f]	—	—	—	—
Phenylalanine	None[h]	—	—	—	—
Aceto-nitrile	—	—	—	—	—
Isatin	—	—	—	—	None
Globulin	—	—	—	—	None
Urea	None	10–100,000[i]	—	—	None
Acetamide	None	Moderate	—	—	Slight
Creatinine	—	—	—	—	None
Sarcosine	—	—	—	—	None

[a] Basic medium, 0.1 per cent glucose plus minerals. Concentration, 1,000 ppm.
[b] Basic medium, 1 per cent glucose plus minerals. Concentration, 100 and 1,000 ppm.
[c] Basic medium, 0.2 per cent meat extract. Concentration, 100 ppm.
[d] Basic medium, 0.1 per cent KNO_3 plus minerals. Concentration, 1,000 to 1,900 ppm (1×10^{-2} M).
[e] Basic medium, 0.5 per cent dextrose plus minerals. Concentration, 100 ppm.
[f] L.
[g] D.
[h] DL.
[i] 0.5 per cent glucose as carbon source.

the sewage was fortified with glucose and starch. Wuhrmann (46) attempts to explain this by asserting that tryptophane, cystine, and methionine strongly retard growth as soon as their concentration amounts to 0.002 to 0.005 ppm. From the total amino acid content of sewage, he infers that these concentrations are present and limit the growth of *Sphaerotilus*. Liebmann agrees with this view.

To investigate these assertions, Höhnl (17) tested the effect of 100 ppm of cystine, tyrosine, and tryptophane on *Sphaerotilus* growing in 0.2 per cent meat extract. He found inhibition with tryptophane, but none with tyrosine and cystine. It would be desirable to obtain the results on the action of tryptophane in the concentrations quoted by Wuhrmann—which are 20,000 times as dilute as those investigated by Höhnl. This explanation for the lack of growth of *Sphaerotilus* in sewage does not therefore seem feasible.

Höhnl also found that asparagine and alanine could serve as carbon sources when an additional nitrogen supply (nitrate) was present in the medium. Under such conditions, arginine was moderately available, but methionine, threonine, tyrosine, and

cystine were unavailable. As a result of comparative nutritional studies between *Sphaerotilus* and certain zoogloeal bacteria, Ruchhoft and Kachmar (36) pointed out the difference in the amount of cell material produced per milligram of organic nitrogen taken up from the medium. This value ranged from 22.5 to 34.1 for *Sphaerotilus* and 5.40 to 6.99 for zoogloeal bacteria. If the disappearance of the nitrogen from the medium can be correlated with its incorporation into cell material, these data seem to indicate an efficient utilization of the available nitrogen. The authors consider that this may be a reason for the preferential growth of *Sphaerotilus* in conditions where nitrogen supply is limited. It may also account for the massive growths of the organism in environments with low concentrations of nitrogen.

Vitamin Requirements

The successful cultivation of *Sphaerotilus* in a simple defined medium of a single amino acid, carbohydrate, and minerals indicates that the organism does not require accessory growth factors. This conclusion is confirmed by Wuhrmann and Koestler (47). They observed no improvement in growth with addition of the following vitamins to a medium of amino acids and glucose: aneurin, lactoflavin, nicotinic acid, pyridoxin-pantothenic acid, biotin, folic acid, and p-amino-benzoic acid. Moreover, the addition of these vitamins did not enable the organism to utilize ammonium compounds as their source of nitrogen.

Mineral Requirements

The requirements of the organism for mineral elements has not been studied in detail. Lackey and Wattie (19) reported that good growth could occur in 200 ppm of mineral salts, but that the organism could survive when the minerals existed in a concentration of 5 ppm each of sodium nitrate, potassium dihydrogen phosphate, dipotassium hydrogen phosphate, magnesium sulfate, and calcium chloride. Liebmann (22) asserts without evidence that phosphorus may be a limiting factor in the development.

The presence of *Sphaerotilus* in the tidal portion of rivers has not been reported, and no correlated salinity data with its appearance are available. Butcher (5) asserts that the organism exists in low concentrations of sodium chloride. The effect of high concentrations of salt is confirmed by the cultural observation of Höhnl (17) that partial inhibition of growth resulted with addition of 2,000 ppm of sodium chloride. He also noted inhibition with fifteenth-molar phosphate buffer.

Influence of pH

Generally, *Sphaerotilus* is considered to be characteristic of neutral waters. Bahr (3) and Wuhrmann (48) regard the organism as being capable of withstanding pH values on the alkaline side of neutrality, but not those on the acid side. Höhnl states that the pH range favorable for growth is relatively wide in comparison with other bacteria.

Pure culture work indicates the minimum value for growth to be 6.0. Lackey and Wattie observed slight growth at pH 5.5, but Höhnl found no measurable increase in cell protoplasm at these values even after 10-day incubation periods. The optimum and maximum pH value is difficult to state accurately, since observations differ so widely. Stokes (40) reports growth up to pH 9 or 10 while Höhnl's long cultivated strain gave 93 per cent of the optimum growth even at pH 8. His "wild" strain, however, produced only 25 per cent of the optimum increase at these values. Since all these results are based on laboratory investigation work, and no accurate field data are available, it is not possible to assess the importance of the factor of pH in limiting the development of the organism.

Influence of Temperature

Development of slime infestation of *Sphaerotilus* is often more evident and assumes problem proportions during the cooler times of the year. Observers have been tempted to attribute this solely to a temperature response of *Sphaerotilus*. It is more probable, however, that the effect which temperature has on other factors affecting the development must also be considered.

There are many conflicting reports in the literature of the temperature relations of the organism when grown in pure culture. The following is a summary of the various conclusions:

1. The organism will not grow actively at temperatures below 5°C.
2. The upper limit of growth is in the range of 35 to 40°C, the actual value not well defined.
3. The optimum temperature for growth is difficult to state. On the basis of visual observations, most workers report optimal temperatures varying from 25 to 37°C. In contrast, Höhnl (17) reports an optimum of 10°C for a wild-type strain, and of 15°C for a cultivated strain. This work is notable in that it employs a quantitative estimation of the amount of growth after a 10-day incubation period. The long incubation period may offer an explanation for the lower reported optima. He observed that at the higher temperatures growth takes place very rapidly, but then terminates. At the lower temperatures, growth starts slowly, but reaches a greater total amount of growth.

In considering the temperature optima, it seems possible that a clear differentiation between high initial rate of growth and the accumulation of such growth has not always been made. The observation of Stokes (40) on his cultures at the 30°C optimum, that as the cultures age, the sheaths disintegrate and liberate cells, is an indication of the possibility of greater amounts of fungus being accumulated at the lower temperatures.

Field observations are summed up by Bahr (3), who asserts that temperature requirements of the organism are not as critical as is frequently assumed. He and Liebmann (22) point out that the assumption that *Sphaerotilus* favors low temperature is based on the fact that it develops particularly well in winter, but they rightly state that this may be due to the effects produced on other organisms and not temperature per se. Liebmann notes that at the lower temperatures there may be less competition for nutrients because of the lowered activity of the other organisms. There may also be less activity of epiphytic saprophytes, allowing greater accumulation of the *Sphaerotilus* filaments in the winter than in the summer.

That such factors do not operate in all rivers are indicated by observations of Lincoln and Foster (23) on the Columbia River. Stating that inhibition of growth occurs below 6°C, they noted minimum amounts of growth in December, January, and February, with better growth resulting as the temperature increased. Abundant development appeared at the maximum river temperature of 23°C.

The Influence of Flow

In considering the effect of flow on *Sphaerotilus* growth, it should be remembered that a given river flow affects the following factors: (a) the oxygen supply, (b) the supply of nutrients, and (c) the capacity to support a mass of growth without sinking or detachment.

The meager observations reported, quote a certain river flow as being necessary because of its effect on one of these factors and without adequate consideration of the other two. For example, in investigating the development of the whole community of sewage fungus, Butcher (5) states that oxygen is not a critical factor. Yet

he quotes Kolkwitz in saying that a current of not less than 20 cm/sec is necessary for its inception. Bahr (3) echoes this thought in reporting that the development of *Sphaerotilus* in flowing water is based not on the oxygen supply, but on the organism's need for a high concentration of nutrients. It is difficult to see how these assertions can be supported from field observations, when the flow influences more than the one factor considered.

No well-controlled experiments have been undertaken in which these three variables are considered with respect to a given flow. The following considerations are therefore based on the available incomplete information:

1. The oxygen supply:—With one exception, cultural work indicates that *Sphaerotilus* is an obligate aerobe. Lackey and Wattie (19) failed to obtain growth under anaerobic conditions or in culture solutions where carbon dioxide or nitrogen were substituted for air or oxygen. Because he obtained surface growth of the organism, Stokes assumes it to be aerobic. He also reports growth in stab cultures and asserts that the organism can survive anaerobiosis for long periods of time. The view that *Sphaerotilus* can grow under very low oxygen tensions is confirmed by the work of Ruchhoft and Kachmar (36) who obtained good growth and development with only 0.1 to 2 ppm of dissolved oxygen present in the medium. Wuhrmann's (48) statement that the oxygen requirement depends upon the available carbon source supplied needs experimental confirmation. Field observations indicate that *Sphaerotilus* appears in oxygen-saturated water as well as locations where there is little oxygen. Wuhrmann states that only in pure culture does the organism thrive at its lowest oxygen tension. It is difficult to state what its lower limit is. Gaufin and Tarzwell (15) noted maximum *Sphaerotilus* in a creek where the minimum dissolved oxygen was 0.5 ppm, but they give no information on the precise areas of growth of *Sphaerotilus* in such a location. Liebmann (20) states that *Sphaerotilus* does not appear in oxygen-poor waters. He further states that wherever the water flows slowly, *Sphaerotilus* growth appears at those locations where the water stands in contact with the air and therefore contains oxygen. Indications in the literature show that in highly polluted waters, otherwise devoid of oxygen, *Sphaerotilus* may be observed growing where there is riffling of the water or periodic inundation. This infers a micro-environmental effect, which has been incompletely studied in this report.

In rivers where there is dissolved oxygen to its depths, i.e. where the pollution is such that oxygen does not become depleted, or where surface reaeration is extensive, *Sphaerotilus* may occur on the stream bed. Liebmann quotes a figure of 50 cm depth for such conditions to prevail. This figure will be modified in different streams by differences in flow and pollution load.

Naumann (29) attempted to obtain information on the oxygen utilization of *Sphaerotilus*. He measured the oxygen depletion of water containing a certain amount of *Sphaerotilus* when it was suspended in previously aerated tap water. The experiments were carried out in stationary cultures, at a temperature of 22°C. With no supply of nutrients and conditions comparable to those in the stream, the results he obtained cannot be applied to the oxygen demand of living or decomposing *Sphaerotilus*.

2. The supply of nutrients:—In experimental troughs receiving Columbia River water, Lincoln and Foster (23) dosed waste sulfite liquor at various concentrations and at constant flow. *Sphaerotilus* growths appeared spontaneously in two days where the concentration of waste sulfite liquor was

TABLE IV.—Comparison of *Sphaerotilus* Growth in Spent Sulfite Liquor with Variable Contact Times

BOD Applied in Feed (ppm)	Feeding Interval (hr)	Resting Interval (hr)	Total BOD Added in 24 hr (ppm)	Slime Volume (ml)
7.7	4	20	30.8	30
5.1	6	18	30.6	50
3.9	8	16	29.6	720

over 100 ppm. None was present in concentrations of 25 ppm even after 7 days. At 500 ppm the growths were heaviest. At a given river flow, therefore, and all other things being equal, the amount of growth will be proportional to the concentration of the available food material. It should be recognized that a limit to this generalization is set by the effect of such food material upon other factors, e.g. the oxygen tension.

In constant flow channels, Amberg and Elder (2) investigated the difference in amounts of *Sphaerotilus* produced when spent sulfite liquor was discharged over different time intervals. They applied equivalent daily BOD loadings of ammonia and calcium-base spent sulfite liquors over different time durations. The growth of *Sphaerotilus* was estimated after 7 days in terms of volume in a cylinder it occupied. They showed conclusively that the amount of growth corresponded to the duration of feeding and not to the total BOD load.

Table IV is taken from their results.

From the results, it appears that the amount of growth is not only proportional to the quantity of available food material, but is dependent also on the time interval over which this food is available.

In considering two rivers of equal nutrient loadings and different flows, it appears that the higher total load of the faster river will be manifested in occurrence of growth over a longer distance rather than in greater amounts of growth at a given location. It may also be concluded that per unit distance of growth appearance, the slower river will result in a greater amount of growth. Liebmann (22) confirmed this when he showed in the lower Main that there were 71 tons of *Sphaerotilus* present with a flow of 72 kg per day, and 325 tons with a flow of 16.2 kg. It should be noted that these figures are quoted without comparative nutrient loadings.

Another factor to be considered in attempting to evaluate the effect of the total load upon the slime growth is that the food available to the organism is predetermined by the surface upon which the growth occurs, i.e. the total amount of food in a river is of lesser importance than that available at the exact location of growth.

3. Capacity to support a mass of fungus without sinking or detachment: —It is convenient at this point to consider the question of attachment of the organism.

Zobell (51)(52) and others have shown that surface attachment has a beneficial effect in dilute solution by functioning to concentrate the nutrients and permit more growth. In a recent publication, Renn (34) discusses this phenomenon with regard to biological slime formation.

Lackey and Wattie (19) are the only observers who report that in pure culture a small terminal disc of the filament functions as an attachment organ for *Sphaerotilus*. However, all other observations indicate that for the appearance of the long, plumose growths associated with heavy infestation, attachment is necessary. The surfaces which can function can be any of the following: the stone or gravel of the river bed, the vegetation of the river

bank, pilings, timbers, wharf-piles, cement structures, boat hulls, fish nets, floating objects, such as cellulose fibers, or other organisms such as diatoms. Floating flocs may attain a large size and form huge "streamers."

The river flow may function in the detachment or in the settling of such growths. They may become detached in a number of ways: (a) High river flows and consequent mechanical disruption were observed by Lincoln and Foster (23) in the Columbia River to be the cause of large numbers of small floating flocs. Such fragments may find a secondary attachment and recommence to grow, as Butcher *et al.* (6) saw in the River Lark. (b) When a periodic pollution is involved, the growths are observed to decompose and become detached when the pollution ceases. Popp and Bahr (31) record the decomposition of attached *Sphaerotilus* as a result of cessation of the beet sugar season in the river system of the Oker. Following this, there were small floating flocs in the river for some time afterwards. Lincoln and Foster noted that when the flow of waste sulfite liquor into their experimental channels was stopped for two days, all traces of *Sphaerotilus* disappeared. The growth soon became gelatinous and lost its plumose appearance where it was once abundant. Flocs which had developed to several centimeters broke loose and were washed away. (c) Detachment may also occur without either of the preceding agents. A floc may become of such dimension that the original attachment portion loses its free access to nutrients or oxygen and, therefore, undergoes decomposition. At this stage, the whole floc is detached, even though the peripheral portion may be living. A living growth may also be detached when its mass is such that the river fails to support it.

Liebmann (21)(22) states that in large deep rivers about two-thirds of the total living fungus drifts near the river bed. These figures were quoted from data on a river where he also found definite under-stratification of the promoting sulfite liquor. It seems possible that the greater amount of food caused the accumulation of fungus at this depth. The dissolved oxygen figures he records (which are not detailed) indicate the river to contain oxygen up to 75 per cent saturation.

The settling of detached organisms gives rise to the secondary pollutional effects. The primary result is depletion of oxygen; without its specific nutrients, the organism undergoes decomposition and thus imposes an excessive demand on the oxygen resources of the stream. The resulting anaerobic conditions, apart from yielding conditions offensive to the public, may result in fish kills, because of the concentration of hydrogen sulfide which is reached. On the basis of his sampling procedures, Liebmann (21) calculated that from a daily production of 100 tons of pulp by the sulfite process, a daily growth of 70 tons could be anticipated.

II. *LEPTOMITUS*

Morphology and Taxonomy

Leptomitus lacteus is a member of the most abundant order of aquatic fungi, the Saprolegniales. It has numerous synonyms, of which the most frequently used and referred to is *Apodya lactea*. Detailed descriptions are given in Coker's (10) monograph on the family Saprolegniales. Its main identifying characteristics are as follows: (a) the width of the filament varies from 8 to 16 μ, while the length may exceed 400 μ; (b) no cells are visible, although the organism has characteristic constrictions which give it a pseudoseptate appearance. These con-

strictions are a result of the presence of cellulin plugs, whose function is unknown.

The appearance in the stream is similar to that of *Sphaerotilus*. An experienced observer can, however, differentiate between the two by the coarser nature of the filaments of *Leptomitus*, and the absence of the mucilaginous nature of the flocs. Naumann (27) reports that the plumes have a symmetrical appearance radiating from a central portion.

Carbon Requirements

Leptomitus has been most frequently recorded as occurring below domestic sewage pollution. Butcher records the species present below an outfall from a beet sugar effluent.

Kolkwitz (18) states that the presence of carbohydrates is unnecessary to the growth of the organism and the pure culture work of Schade (37) confirms this view. In the presence of an amino acid nitrogen source, he demonstrated that glucose, levulose, galactose, sucrose, and maltose could not serve as carbon sources. This contention is not entirely satisfactory, however, since they report increased growth when 1 per cent glucose is added to a stock medium of peptone and gelatine. Without experimental evidence, they attribute the beneficial effect of its addition to its action in nullifying such inhibitive substances as may be excreted by the fungus in its growth. With the exception of formic and propionic acids, all the straight chain fatty acids up to and including caproic acid were utilizable. Salts of fumaric, succinic, and malic acid were unavailable, but lactic acid was utilized.

Schade and Thimann (38) also studied the efficiency of assimilation of the carbon compounds. From the amount of oxygen uptake, they found that only 33 per cent of acetate added to the medium was oxidized before the respiratory rate returned to the original "basal-level." A second addition of acetate caused an immediate rise in respiration level. They therefore assumed that the remaining two-thirds of the acetate must have disappeared, and deduced that this represented the assimilated part of the acetic acid. On this basis, the fungus has a very high oxidative efficiency compared to other organisms. This is an attractive theory to account for the ability of the fungus to grow well in very dilute media. The evidence offered, however, is not conclusive. The assimilation of acetate was based upon oxygen uptake and not upon the amount of organic carbon fixed as cell protoplasm. The remaining two-thirds of the acetate may have been represented in the medium as unavailable residue.

Nitrogen Requirements

It is repeatedly stated in the literature that *Leptomitus* requires high molecular compounds of nitrogen to supply its needs for this element.

Kolkwitz (18) early described the non-utilization of inorganic nitrogen in the presence of sugars. His views were refuted by the later work of Tromsdorff (43) who reported that growth did occur in solutions containing inorganic sources of nitrogen. Dorries and Haase (14), however, point out that Tromsdorff did not adequately wash the filaments before transference, so that their growths in inorganic nitrogen media were due to carry-over from the original liquid containing peptone and meat extract. With good washing of the filaments, these workers failed to demonstrate growth with inorganic sources of nitrogen.

In more recent work, Schade (37) confirmed that no growth occurred with ammonium, nitrate, or nitrite compounds, even in the presence of available carbon compounds. In his work, Schade defines more specifically the utilizable nitrogen compounds. Al-

though he tested only four amino acids, his results clearly indicate the utilization of decomposition products of proteins. With an additional carbon source present, the organism could grow when glycine or asparagine was the nitrogen source; L-leucine and DL-alanine could function without accessory carbon compounds. In respiratory studies, Schade and Thimann (38) demonstrated that without additional carbon source, the available amino acids were deaminated, to give free ammonia when an available carbon source was also present. There was a decrease in the ammonia formed; presumably it was being used for synthetic purposes. In the presence of an amino acid and a carbon compound, ammonia was actively absorbed by the mycelium. Of the ammonia absorbed under such circumstances, only 11.5 per cent could be accounted for on the basis of simple accumulation. They deduce, therefore, that part of the protoplasm can be synthesized from a carbon source and an ammonium compound, but the amino acid donates some vital part. No studies on the effect of growth factors have been undertaken.

Their experiments utilized the loss of ammonia from the medium, rather than its transformation into organic nitrogen within the cell as a criterion for its assimilation. It would be informative to compare the weight of organic nitrogen formed when different concentrations of amino acid and ammonia were available. This could indicate whether the amino acids were functioning in a capacity other than that of a nitrogen source and, whether in these conditions, ammonia could serve as a nitrogen source.

In field observations, Weston and Turner (44) noted a variation in the ammonia content of the water with appearance of *Leptomitus*. When the organism was present, the concentration of ammonia was less than 6 ppm, when the organism was absent, the concentration of ammonia was more than 8 ppm. In cultural studies, however, Tiegs and Dorries (42) noted no inhibitory influence of 8 ppm of ammonia when the filaments were suspended in peptone medium. At 74 ppm of ammonia, there was some damage to the cells and, at 250 ppm, there was total death. In liquid media, Schade and Thimann (38) found that an initial retardation of growth occurred when the ammonium ion was present, but his effect was nullified with long incubation periods. There does not appear to be adequate experimental evidence of any inhibitory effect of ammonia on the organism's development.

Mineral Requirements

In a solution containing potassium phosphate, magnesium sulfate, and sodium acetate, Schade (37) obtained good growth with 14 ppm sodium, 97 ppm potassium, 77 ppm phosphorus, 12 ppm magnesium, and 16 ppm sulfur. He noted some inhibition of growth with higher concentrations of potassium dihydrogen phosphate than 0.003 ppm, but investigated the action no further. This species of the Saprolegniales apparently differs from other members investigated in being able to utilize sulfate as a source of sulfur.

pH

More information on the pH tolerance of the organism is available. Tiegs and Dorries (42) investigated the growth in buffers with different pH ranges. They found that growth took place at a minimum pH of 2.5, and a maximum of 7.5, with an optimum of 2.9 to 5.4. Schade (37) quotes a suitable pH range of 4.3 to 7.5, with an optimum of 5.4 to 6.0. This postulated preference by *Leptomitus* for conditions on the acid side led Wuhrmann to conclude this was the reason why it never occurred side by side with *Sphaerotilus* in an infestation. It has been reported, however, that both organisms

can occur together, although perhaps not in equal amounts in a given infestation.

The literature contains few descriptions of field conditions existing when infestations of *Leptomitus* occur; the paucity of information probably indicates its lesser frequency.

Temperature

The temperature relations of the organism reported by Kolkwitz (18) when growing in pure culture are confirmed by Schade (37) in recent work. He quotes an optimal range of 18 to 25°C, with very slight growth at 0°C. Field observations by Weston and Turner (44) indicated that in a stream receiving a partially purified sewage effluent, the organism appeared first in infestation proportions in December when the temperatures ranged from 5 to 6°C, and disappeared in early summer with temperatures of 16 to 18°C. They relate its appearance at these low temperatures with the indirect effects of the low temperatures. They point out, for example, that, correlated with temperature, the dissolved oxygen during the growth period was greater than 6 ppm, while during the summer period it was consistently less than this. The only reference to the oxygen requirements of the organism is that of Schade (37) who observed no growth under anaerobic conditions. He noted, however, that *Leptomitus* remained viable for at least 10 days under these conditions.

III. SUMMARY AND CONCLUSIONS

1. With few exceptions, slime infestations in streams are the result of an excessive growth of either a sheathed, filamentous bacterium, *Sphaerotilus natans,* or of a true aquatic fungus, *Leptomitus lacteus.*

2. Sudden development arises from growth of resistant stages in the life history of the organism already present in the water course. In the case of *Sphaerotilus,* it may arise from the non-mucilaginous dichotomous form, *Cladothrix dichotoma,* or from motile conidia. The conditions which give rise to the production of the mucilaginous sheath of *Sphaerotilus* seem to be important in allowing the aggregation of a large number of filaments to occur.

3. A variety of other microorganisms may find a suitable habitat in the flocs of the two organisms. They may be secondary invaders, but there is no evidence that any play a significant part in limiting or stimulating the development.

4. A wide variety of organic compounds can serve as carbon sources for *Sphaerotilus:* (a) mono- and disaccharides, (b) organic acids, (c) alcohols, and (d) amino acids. *Leptomitus* can utilize certain organic acids; existing experimental evidence indicates that sugars are unavailable. More information is needed on this subject.

5. Cultural experiments show that fairly good growth of *Sphaerotilus* results when nitrate is the nitrogen supply. There is some evidence that the utilization of ammonium compounds depends on the carbon supply; other evidence indicates that excess ammonia is inhibitory. For luxurious growth, an organic nitrogen supply is necessary. This can be supplied by a wide range of amino acids. *Leptomitus* cannot grow when ammonium or nitrate salts are the sole source of nitrogen. Certain amino acids can be used; when these are present, there are indications that the organisms can also assimilate ammonium salts.

6. *Sphaerotilus* does not require accessory growth factors for its develop-

ment. Information on this aspect of the nutrition of *Leptomitus* is lacking.

7. Experimental work to define the mineral requirements of the two organisms has not been undertaken. There are indications that too high a concentration of salts (e.g., as in sea water) may be inhibitory.

8. *Sphaerotilus* prefers environments of pH above 6.0, and can withstand alkaline conditions at least to pH 8.0. *Leptomitus* can exist below pH 2.5, with an optimum pH of 5.4 to 6.0. If this is the factor determining the preferential development of one organism over the other, the range of mutual exclusiveness must be very narrow and implies a competition for nutrients.

9. Both types of infestations are often more obvious in the cold months of the year. Cultural work indicates that this is not simply a temperature response of the organism. The seasonal manifestations may be due to the better oxygen supply, or to greater accumulation because of reduced metabolic activity.

10. Cultural work indicates that both species require an aerobic environment for their development. Although field observations are recorded of the occurrence of *Sphaerotilus* in waters of oxygen tensions of less than 1 ppm, there is no evidence on which to reject the view that the oxygen actually available to the growing organism may be more than this.

11. The effect of flow is three-fold. Where oxygen is the limiting factor in development, the effect of flow is to enhance the growth. There is evidence that growth is directly proportional to the concentration of available food; some evidence that it is not proportional to the total load. Where food only is limiting, the highest amount of growth per unit distance, therefore, will be found in rivers with the lower flow. Higher flows result in growth occurring over a longer river distance.

12. Field investigations indicate that detachment of living and non-living growths may occur. The factors leading to detachment may be: (a) scouring velocities, (b) cessation of food supply, (c) decomposition of an attached portion, or (d) an excessive growth with respect to the given river flow. Growth of detached floating flocs is not significant. If any become secondarily attached, a secondary area of infestation results.

13. The contention that the reason for the non-appearance of *Sphaerotilus* in direct proximity to sewage outfalls is due to an inhibitory concentration of amino acids is not confirmed by pure culture work.

14. There is some evidence that the massive growths may be due to the inherent ability of the organisms to utilize efficiently the available carbon and nitrogen sources.

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References

1. Agersborg, H. P. K., and Hatfield, W. D., "The Biology of a Sewage Treatment Plant—A Preliminary Survey—Decatur, Illinois." *Sewage Works Jour.*, **1**, 4, 411 (July 1929).
2. Amberg, R. H., and Elder, R., "Intermittent Discharge of Spent Sulphite Liquor." *Jour. San. Eng. Div., Amer. Soc. Civil Engrs.*, **82**, SA2, 929 (1956).
3. Bahr, H., "The Biology of *Sphaerotilus natans*." *Schweiz. Z. Hydrol.* (Switzerland), **15**, 285 (1953).
4. Beger, H., and Bringmann, G., "The Structure of the Sheath of the Sewage-bacterium *Sphaerotilus* and the Non-bacterium *Leptothrix* by Electron Microscopy, and Their Significance in the Taxonomy of These Species." *Zentr. Bakteriol. Parasit.* (Germany), II, **107**, 318 (1953).
5. Butcher, R. W., "Contribution to Our Knowledge of the Ecology of Sewage Fungus." *Trans. Brit. Mycol. Soc.*, **17**, 112 (1932).

6. Butcher, R. W., Pentelon, F. T. K., and Woodley, J. W. A., "An Investigation of the River Lark and the Effect of Beet-Sugar Pollution." Fishery Investig. Series 1, 111, No. 3 (1940).
7. Cataldi, M. S., "A Study of the Systematics of the Chlamydobacteriales." Thesis, Univ. Buenos Aires (Argentina) (1939).
8. Cooke, W. B., "The Use of Antibiotics in Media for the Isolation of Fungi from Polluted Water." *Antibiotics and Chemotherapy*, **4**, 6 (1954).
9. Cooke, W. B., "Fungi in Polluted Water and Sewage. I. Literature Review. II. Isolation Technique. III. Fungi in a Small Polluted Stream." THIS JOURNAL, **26**: 4, 539; 5, 661; 6, 790 (Apr., May, June 1954).
10. Coker, W. C., "The Saprolegmaceae." Univ. of North Carolina Press (1923).
11. Crosby, E. S., "Slime Growth on Submerged Surfaces in Sewage and Refinery Waste." Thesis, Rutgers University (1953).
12. De Martini, F. E., "Slime Growths in Sewers." *Sewage Works Jour.*, **6**, 5, 950 (Sept. 1934).
13. Demoll, R., and Liebmann, H., "The Distribution of *Sphaerotilus natans* in Rivers." *Schweiz. Z. Hydrol.* (Switzerland), **14**, 289 (1952).
14. Dorries, W., and Haase, L. W., "The Influence of the Hydrogen Ion Concentration on the Growth of *Leptomitus lacteus* in Artificial Nutrient Media." *Kl. Mitt. Mitg. Ver. Wasser-, Boden-, U. Lufthyg.* (Germany), **6**, 240. Append. (1930).
15. Gaufin, A. R., and Tarzwell, C. R., "Aquatic Macro-invertebrate Communities as Indicators of Organic Pollution in Lytle Creek." THIS JOURNAL, **28**, 7, 906 (July 1956).
16. Harvey, J. V., "Relationship of Aquatic Fungi to Water Pollution." THIS JOURNAL, **24**, 9, 1159 (Sept. 1952).
17. Höhnl, G., "Investigation into the Physiology and Nutrition of *Sphaerotilus natans*." *Arch. Mikrobiol.* (Germany), **23**, 207 (1955).
18. Kolkwitz, R., "The Biology of *Leptomitus lacteus*." *Ber. Deutsch. Bot. Ges.* (Germany), **19**, 288 (1901).
19. Lackey, J. B., and Wattie, E., "Studies of Sewage Purification. XIII. The Biology of *Sphaerotilus natans* (Kutzing) in Relation to the Bulking of Activated Sludge." *Public Health Repts.*, **55**, 975 (1940).
20. Liebmann, H., "Effect of Waste Liquor from Sulphite-Pulp Mills upon Stagnant Waters." *Gesundh.-Ing.* (Germany), **60**, 517 (1937).
21. Liebmann, H., "The Action of Sulphite Cellulose Waste Liquors on Smaller and Larger Streams." *Gesundh.-Ing.* (Germany), **72**, No. 17/18 (1951).
22. Liebmann, H., "The Biological Community of *Sphaerotilus* Flocs and the Physico-Chemical Basis of Their Formation." *Vom Wasser* (Germany), **20**, 24 (1953).
23. Lincoln, J. H., and Foster, R. F., "Investigation of Pollution in the Lower Columbia River." Washington State Pollution Commission and Oregon State Sanitary Authority (1943).
24. Littman, M. L., "Carbon and Nitrogen Transformations in the Purification of Sewage by the Activated Sludge Process. IV. With a Culture of *Sphaerotilus*." *Sewage Works Jour.*, **12**, 4, 685 (July 1940).
25. Naumann, E., "Report on the Ecology of Fresh-Water Algae. IV. The Algae-Aufwuchs of *Sphaerotilus natans*; V. The Algae-Aufwuchs of *Leptomitus lacteus*." *Ark. für Botanik*, 25A (1933).
26. Naumann, E., "An Evaluation of the Aufwuchs of *Sphaerotilus natans* (Kutzing)." *Arch. Hydrobiol.* (Germany), XXV, 407 (1933).
27. Naumann, E., "Growth Forms of the Sewage Fungus *Leptomitus lacteus* (Roth) Agardh." *Ber. Deutsch. Botan. Ges.* (Germany), **51**, 99 (1933).
28. Naumann, E., "Is *Cladothrix dichotoma* Identical with *Sphaerotilus natans* (Kutzing)?" *Zentr. Bakteriol. Parasit.* (Germany), 2 Abs. 88 (1933).
29. Naumann, E., "*Sphaerotilus* Aufwuchs as a Purifying and Polluting Agent of Flowing-Waters." *Arch. Hydrobiol.* (Germany), XXVI, 472 (1934).
30. Odum, E. P. "Fundamentals of Ecology." W. B. Saunders Co. (1953).
31. Popp, L., and Bahr, H., "The Massive Development of *Sphaerotilus natans* and Its Entry into the River System of the Oker During the Sugar Campaign of 1952." *Wasserwirtschaft* (Germany), **45**, 2, 29 (1954).
32. Potonie, H., and Wundsch, H. H., "Quantitative Values and Typical Manifestation of Floating Sewage Fungus." *Zeits. Fischerei* (Germany), **31**, 379 (1933).
33. Pringsheim, E. G., "The Filamentous Bacteria *Sphaerotilus, Leptothrix, Cladothrix*, and Their Relation to Iron and Manganese." *Philos. Trans. Roy. Soc. London, Ser. B*, No. 605, **233**, 453 (1949).

34. Renn, C. E., "Biological Treatment of Sewage and Industrial Wastes." Reinhold Publ. Corp., New York, N. Y. (1956).

35. Ruchhoft, C. C., and Watkins, J. H., "Bacteriological Isolation and Study of the Filamentous Organisms in the Activated Sludge of the Des Plaines River Sewage Treatment Works." *Sewage Works Jour.*, **1**, 1, 52 (Oct. 1928).

36. Ruchhoft, C. C., and Kachmar, J. F., "Studies of Sewage Purification. XIV. The Role of *Sphaerotilus natans* in Activated Sludge Bulking." *Sewage Works Jour.*, **13**, 1, 3 (Jan. 1941).

37. Schade, A. L., "The Nutrition of *Leptomitus*." *Amer. Jour. Botany*, **27**, 376 (1940).

38. Schade, A. L., and Thimann, K. V., "The Metabolism of the Water Mould, *Leptomitus lacteus*." *Amer. Jour. Botany*, **27**, 659 (1940).

39. Smit, J., "Bulking of Activated Sludge. II. On the Causative Organisms." *Sewage Works Jour.*, **6**, 6, 1041 (Nov. 1934).

40. Stokes, J. L., "Studies on the Filamentous Sheathed Iron-Bacterium—*Sphaerotilus natans*." *Jour. Bact.*, **67**, 278 (1954).

41. Tiegs, E., "Sewage Fungus and the Condition of Water." *Vom Wasser* (Germany), **13**, 78 (1938).

42. Tiegs, E., and Dorries, W., "The Utilization of Inorganic Nitrogen Compounds by *Leptomitus*." *Kl. Mitt. Mitg. Ver. Wasserversorg. Abwasser beseitigung.* (Germany), **2**, 105.

43. Tromsdorff, R., "The Growth Conditions of the Sewage Fungi *Leptomitus* and *Sphaerotilus*." *Zentr. Bakteriol.*, **11**, Abs. 48, 62, (1918).

44. Weston, R. S., and Turner, C. E., "Studies on the Digestion of a Sewage-Filter Effluent by a Small and Otherwise Unpolluted Stream." Contr. Sanit. Res. Lab., Mass. Inst. Tech., **10**, 1 (1917).

45. Weston, W. H., "The Role of the Aquatic Fungi in Hydrobiology." Symposium on Hydrobiology, Univ. of Wis. Press, Madison, Wis. (1941).

46. Wuhrmann, K., "Amino Acid Content of Raw and Purified Sewage." *Verh. Int. Ver. Limnol.* (Switzerland), **10**, 580 (1949).

47. Wuhrmann, K., and Koestler, S., "The Vitamin Requirements of the Sewage-Bacterium *Sphaerotilus natans*." *Ver. Schweiz. Naturf. Gesell.* (Davos) (Switzerland), 177 (1950).

48. Wuhrmann, K., [Title Unknown]. *Ver. Schweiz. Naturf. Gesell.* (Zurich), **126**, 142 (1948).

49. Wuhrmann, K., "High-Rate Activated Sludge Treatment and its Relation to Stream Sanitation. II. Biological River Tests of Plant Effluents." THIS JOURNAL, **26**, 2, 212 (Feb. 1954).

50. Zikes, H., "Comparative Investigation on *Sphaerotilus natans*." *Centr. Bakteriol.*, **43**, Abs. 2, 529 (1915).

51. Zobell, C. E., "The Effect of Solid Surfaces Upon Bacterial Activity." *Jour. Bact.*, **46**, 39 (1943).

52. Zobell, C. E., and Grant, C. W., "Bacterial Activity in Dilute Nutrient Solutions." *Science*, **96**, 2486, 189 (1942).

Additional References *

Bartsch, A. F., "Biological Aspects of Stream Pollution." *Sewage Works Jour.* **20**, 2, 292 (Mar. 1948).

Bartsch, A. F., and Churchill, W. S., "Biotic Responses to Stream Pollution During Artificial Stream Re-aeration." Amer. Assn. Advance. Sci., Limn. Aspects of Water Supply and Waste Disposal, 33 (1949).

Beardsley, C. W., "Suppression of Sewer Slimes." *Sewage Works Jour.*, **21**, 1, 1 (Jan. 1949).

Bell, H. D., "Research on the Composition of the Grey Slimy Growth on the Surface of Sewage Filters." *Surveyor* (British), **70**, 561 (1926).

Brinley, F. J., "Biological Studies, Ohio River Pollution Survey. I. Biological Zones in a Polluted Stream." *Sewage Works Jour.*, **14**, 1, 147 (Jan. 1942).

Brinley, F. J., "Sewage, Algae, and Fish." *Sewage Works Jour.*, **15**, 1, 78 (Jan. 1943).

Gennerich, J., "Contributions to the Nutritional Physiology and Systematics of the Sewage Fungi. *Leptomitus lacteus* (Roth) Agardh. and *Sphaerotilus natans* (Kutzing)." *Bes. Mitt. Dtsch. Gewasserkundlichen. Jb.* (Germany), **4**, 134 (1952).

Gennerich, J., and Sikora, E., "Pollution of the Main and the Rhine, Expressed by Quantitative Determination of Drifting Sewage Fungus." *Wasserwirtschaft.* (Germany), **42**, 180 (1952).

Goudey, R. F., "Outfall Sewer Experiences in Imperial Valley." *Eng. News-Rec.*, **98**. 648 (1927).

* Not quoted in the text but related to the subject.

Hesseltine, C. W., "Study of Trickling-filter Fungi." *Bull. Torrey Botanical Club*, **80**, 507 (1953).

Kolkwitz, R., "The Structure and Form of *Leptomitus lacteus*." *Ber. Deutsch. Botan. Ges.* (Germany), **21**, 147 (1903).

Kolkwitz, R., "Ecology of the Relations of the Environment on the Aquatic Organisms." *Schrift. Ver. Wasser-, Boden-, u. Lufthyg.* (Germany), **4**, (1952).

Lackey, J. B., "On the Biological Aspects of Papermill Pollution in Certain Parts of the Columbia River Watershed with Especial Reference to *Sphaerotilus natans*." Preliminary Report, USPHS (1941).

Liebmann, H., "Causes of Large Annual Fish Mortality in Bleiloch Barrier on the Saale River." *Allgem. Fischerei Ztg.* (Germany), **63**, 6, 88 (1938).

Liebmann, H., "Effect of Sulphite Pulp Liquors Upon Chemistry of Bleiloch Barrier, Upper Saale River." *Vom Wasser* (Germany), **13**, 58 (1938).

Liebmann, H., "Biochemical Studies of Sulphite Waste-Liquor Decomposition." *Gesundh.-Ing.* (Germany), **62**, 515 (1939).

Liebmann, H., "The Influence of Waste Liquor of the Cellulose Manufacturing Industry on Fish." *Monatsh. Fischerei* (Germany), **11**, 122 (1940).

Liebmann, H., "The Influence on Fish of Water Polluted by the Wood-Saccharifying Industry." *Zeits. Fischerei* (Germany), **39**, 2, 285 (1941).

Lönnerblad, A., Naumann, E., and Wanselin, J., "The Oxygen Consumption of *Sphaerotilus*-aufwuchs." *Botan. Notiser* (Sweden), 577 (1933).

Lönnerblad, G., and Naumann, E., "Experiments in the Oxygen Consumption of Organically Polluted Water With and Without Inoculation of Saprophytes." *Botan. Notiser* (Sweden), 581 (1933).

Lönnerblad, G., and Naumann, E., "The Chemical Composition and Quantitative Development of the *Sphaerotilus* Aufwuchs in Motala Strömen." *Botan. Notiser* (Sweden), 581 (1933).

Naumann, E., "The Normal Type of *Sphaerotilus natans* (Kutzing) and its Modifications." *Ber. Deutsch. Botan. Ges.* (Germany), **50**, 558 (1932).

Naumann, E., "The Slime-Layer of *Sphaerotilus natans* as a Temporary Phenomenon of the Normal Habit." *Zentr. Bakteriol. Parasit.* (Germany), 2 Abs. 88 (1933).

Painter, H. A., "Factors Affecting the Growth of Some Fungi Associated with Sewage Purification." *Jour. Gen. Microbiol.*, **10**, 177 (1954).

Ruchhoft, C. C., Kachmar, J. F., and Moore, W. A., "Studies of Sewage Purification. XI. The Removal of Glucose from Substrates by Activated Sludge." *Sewage Works Jour.*, **12**, 1, 27 (Jan. 1940).

Sparrow, F. K., "Aquatic Phycomycetes." Univ. Mich. Press, Ann Arbor, Mich. (1943).

Trient Fishery Board, Annual Reports (1950) (1951).

Tulloch, G. S., "A New Record of *Leptomitus* from Alaska." *Torreya*, **34**, (1934–6).

Vichl, K., "Effect of Temperature on the Self-Purification of Streams with Especial Reference to the Bacteriological Changes." *Zeit. Hyg. Infektkr.* (Germany), **122**, 81 (1939).

Wiley, A. J., Parkinson, L., Gehm, H., Wisniewski, T. F., and Bartsch, A. F., "River Reaeration." *Paper Trade Jour.*, **124**, 12, 59 (1947).

Wilson, J. N., "Microbiota of Sewage Treatment Plants and Polluted Streams." Amer. Assn. Advance. Sci., Limn. Aspects of Water Supply and Water Disposal (1949).

Wuhrmann, K., "The Testing of Biologically Purified Sewage Effluents." *Gesundh.-Ing.*, **72**, 253 (1951).

THE OPERATOR'S CORNER

PRIMARY CLARIFIER OPERATING GUIDE

By Robert E. Leaver

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Regardless of the elaborateness of the primary clarifier, operational problems arise that only the operator can cure. Since solids removal is basic to most of the other treatment operations, time spent in remedying these problems usually pays large dividends.

Table I lists some common operating conditions and possible remedies. In attempting to find the cause of the condition only physical appearance, settleable solids, and dissolved oxygen information are used. Equipment for determining settleable solids and dissolved oxygen content is very inexpensive and within the means of any

TABLE I.—Symptoms and Remedies for Primary Clarifiers

Settleable Solids, Effluent (ml/l)	Dissolved Oxygen (ppm)		Physical Condition	Probable Cause of Condition	Possible Remedy*
	Infl.	Effl.			
Trace—0.3	>2.0	>2.0	Excellent	—	—
Trace—0.3	>2.0	2.0–0.1	Fair	Warm or strong sewage	1,2,3
Trace—0.3	>2.0	None	Unsat.	Warm or strong sewage	1,2,3
Trace—0.3	2.0–0.1	>2.0	Good	Cold or weak sewage	—
Trace—0.3	2.0–0.1	2.0–0.1	Poor	Stale raw sewage	1
Trace—0.3	2.0–0.1	None	Unsat.	Warm stale strong sewage	1,2,3
Trace—0.3	None	>2.0	Good	Septic cold or weak sewage	4,5,6
Trace—0.3	None	2.0–0.1	Poor	Septic sewage	2,4,5,6
Trace—0.3	None	None	Very bad	Warm strong septic sewage	1,2,3,4,5,6
>0.3	>2.0	>2.0	Poor	Too much sewage	7
>0.3	>2.0	2.0–0.1	Poor	Too much strong sewage	7,2,3
>0.3	>2.0	None	Unsat.	Overloaded (hydraulically and organically)	2,3
>0.3	2.0–0.1	2.0	Poor	Too much stale cold sewage	7
>0.3	2.1–0.1	2.1–0.1	Poor	Too much stale sewage	2,7
>0.3	2.1–0.1	None	Unsat.	Too much stale or warm strong sewage	2,3
>0.3	None	>2.0	Fair	Too much septic cold sewage	7,4,5,6
>0.3	None	2.1–0.1	Unsat.	Too much septic sewage	7,2,4,5,6
>0.3	None	None	Terrible	Many reasons	2,3,4,5,6

* For identification of remedy see Table II.

TABLE II.—Operating Remedies

No.	Remedy
1	Increase flow to primary clarifier.
2	Prechlorinate so that no chlorine residual is in the effluent.
3	Aerate or add recirculated liquid high in dissolved oxygen.
4	Add upsewer chlorination so that no chlorine residual is present in plant influent.
5	Flush sewers routinely.
6	Decrease retention time in lift station.
7	Decrease flow to primary clarifier.

plant. One or more of the remedies in Table II may help correct conditions noted in Table I. The correct remedy must often be determined by the process of elimination—a method familiar to all operators.

INTERESTING EXTRACTS FROM OPERATION REPORTS

"Just praise is a debt and should be paid."—Peter B. Kyne

Attention operators! It will be appreciated if copies of the annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Annual Report of the District of Columbia Sewage Treatment Plant for the Fiscal Years 1956 and 1957 *

HUGH A. SCHREIBER, *Superintendent*

The treatment practices during fiscal 1956 and 1957 did not vary from the preceding years. Digesters were cleaned during 1957 for the first time since the plant was placed in operation in 1938.

The average daily sewage flow remained practically at the 1954 and 1955 rates during 1956. Approximately 1,129 mil gal of raw sewage was diverted to the river from February 15 to March 4, 1956, while a sewer was repaired.

The 1957 daily flow averaged 2.1 per cent more than during the preceding year. Beginning October 30, 1956, flow from the Washington Suburban Sanitary District was discharged to the District of Columbia interceptor. From this source an average of 25 mgd has been received. This added flow would have made the sewage flow the largest ever treated; however, during the period of March 25 through June 13, 1957, all except about 100 mgd of the flow received at the plant was by-passed while the digesters were cleaned. The maximum daily flow was 239.3 mil gal on March 1, 1957.

Supervision of the institutional sewage treatment plants of the District of Columbia in the adjacent states of Maryland and Virginia was continued.

Treatment

Grit removal increased from 1.6 to 2.3 cu ft per million gallons of sewage in 1956 and 2.5 cu ft in 1957. The volatile content still averaged high (20.2 per cent) because of the inability to maintain uniform flow in the grit channels.

Suspended solids reductions for the two years were about the same as in 1955, averaging about 50 per cent or slightly more. The efficiency of the BOD reductions continued to decrease slightly, dropping from 28.7 per cent in 1955 to 26.9 and 25.9 per cent, respectively, in 1956 and 1957. Contrary to previous experience, the strength of the incoming sewage remained high during the last several months of 1956, whereas flows were

* For last previous extract see THIS JOURNAL, **28**, 10, 1308 (Oct. 1956).

considerably less than would be expected. Unseasonably cool weather and steadily increasing domestic garbage grinding apparently contributed to this condition. Probably the most significant causes were the elimination of much infiltration of river water into the sewers and a reduction in the discharge of large quantities of air-conditioning water.

The population equivalents for 1956 and 1957 were 1,138,000 and 1,109,000, respectively. The practice of municipal garbage grinding continued and this additional load (7,500 to 9,000 tons per year) is reflected in a higher BOD and population equivalent. The population equivalent for 1957 does not reflect a true value because much of the sewage was by-passed during digester cleaning in April, May, and June. The average population equivalent for the other nine months was 1,233,000, or 8.3 per cent greater than in 1956.

Sludge Digestion and Filtration

Digester cleaning was attempted in 1956 on digester No. 4, but was unsuccessful. In 1958, a new approach was made on digester No. 12 to remove solids while the tank was still in service. High-pressure gas jets and water-flushing nozzles were used with the regular sludge pumps and a torque-flow pump. This method proved too slow.

The remaining 10 digesters were taken out of service and purged with river water to stop the digestion process. The gas dome was removed, a 1-in. fire nozzle was used attached to a pole, and the tank contents were pumped to a specially constructed lagoon. The torque-flow pump performed effectively, moving 15 per cent solids. Details of the cleaning operation were presented in THIS JOURNAL, 29, 11, 1301 (Nov. 1957). The greatest difficulty was encountered in moving the mat of trash and solids. As a partial solution, a specially fitted orange-peel bucket was used with a hydro-crane.

Early in March 1957 the digestion process came to a stop because of inability to heat the digesters properly. Increased load (due to removal of some digesters from service), high solids concentration, winter temperatures, and improper circulation of digester contents contributed to the decrease in digester activity.

Gas production dropped from an average of 700,000 cu ft per day to 230,000 cu ft per day. This was insufficient to operate the sludge-gas engine, which was the principal source of heat for the digesters. A 4-in. high pressure gas line was installed and gas was purchased for the gas engine.

The digester cleaning was completed by June 1957 and seven of the tanks were soon in service. The piping in each digester had become dislodged during the years and required major repairs.

Two-stage elutriation continued to be successful in reducing the alkalinity and producing a consistently heavy sludge. The wash-water ratio varied from 2.4 to 2.8, and produced the same results as a single wash with at least four volumes of wash water.

The sludge drying and incineration plant was not operated during 1956 or 1957, although it had been completed in 1955. Revisions, shown to be necessary by testing, were under way in preparation for final acceptance tests. All of the filter cake was trucked away by farmers and the local governmental agencies, and used for top soil dressing. The sludge that was not used was hauled to a disposal area.

The cloths on the four vacuum filters were replaced each year, after an average of 1,066 and 1,711 filter hours per unit. Use of the 10 per cent nylon and 90 per cent wool filter cloths was continued. The goal of reducing the ferric chloride dose to 3.5 per cent was not reached. The dosage averaged 4.68 per cent in 1956 and 4.81 per cent in 1957.

Chlorination

Use of the extensive automatic chlorinating facilities constructed several years ago was undertaken in September 1955 and continued through mid-November. Chlorination was resumed April 24, 1956, when hot-weather chlorination was carried on. Pre-chlorination dosages ranged from 4 to 13 ppm, and post-chlorination applications ranged from 2 to 4 ppm. Chlorine was used to control odors and obtain bacterial kills. A 15-min chlorine residual of 1 ppm in the final effluent produced a bacterial kill of more than 99 per cent. Chlorination was suspended at the end of August, due to the lack of chlorine, and was not resumed in the spring of 1957 owing to the lack of funds. The 1956 chlorine requirement was 440 tons.

Power Plant

The power plant served the entire treatment plant, providing electrical energy and heat. The plant satisfied 50.6 per cent of the electrical energy requirements in 1956 and 69.5 per cent in 1957. The 1,200-hp sludge-gas engine operated an average of 80 per cent of the time during the two years covered by this extract.

TABLE I.—Comparison of Operation and Maintenance Costs for Fiscal 1955, 1956, and 1957

Item	Costs ($)		
	1955	1956	1957
Administration	30,894	36,971	38,298
Laboratory	19,355	23,688	28,344
Sewage pumping	94,097	134,913	145,532
Grit removal	22,262	20,884	23,711
Grease separation	4,854	7,283	7,183
Grit disposal	2,058	2,310	1,767
Sedimentation	54,271	58,757	210,630
Sludge digestion	24,715	28,041	66,415
Sludge elutriation	6,793	12,594	8,164
Sludge dewatering	73,280	77,551	84,540
Sludge drying	25,627	37,537	49,697
Chlorination	470	38,679	38,529
Shops	4,436	4,256	10,062
Plant grounds	18,901	19,328	28,318
Inventory	12,010	7,719	—
Total	394,023	510,511	741,190
Unit costs:			
Treatment ($/mg)	6.98	6.69	10.14
Pumping ($/mg)	1.62	2.32	2.45

Laboratory

About 23,000 routine analyses were made in the laboratory in 1956, and 28,000 in 1957. Tests included all of the basic sewage treatment plant operating tests (BOD, COD, suspended and settleable solids, etc.) and a number of special tests on sludge and filtration. Sampling of the Potomac and Anacostia Rivers was continued.

During 1956 a more intensive study was made of the operation of the treatment plants, receiving streams, and main laundry at the penal institutions supervised by the District of Columbia sewage treatment plant.

Operating Costs

Actual operating costs are distributed to the specific sewage treatment functions. Power plant operation is charged 85 per cent to electrical energy and 15 per cent to plant heating. The budgetary expense of operation continued to increase. It was $510,511 and $741,190 in fiscal 1956 and 1957, respectively, compared with $394,023 in fiscal 1955. Comparison of operating charges for the three years (1955, 1956, and 1957) is given in Table I.

It should be noted that approximately $10,000 worth of water is furnished by the D. C. Water Division and not paid for directly by the sewage treatment plant. In addition, an estimated $9,829 worth of services and materials was supplied by other branches of the Department of Sanitary Engineering, District of Columbia government, in 1956. Payments were received from the Naval Research Laboratory, adjacent to the treatment plant, for digester gas supplied during the years.

The operational charges for pump-

TABLE II. Summary of Operating Data for the Fiscal Years 1956 and 1957, District of Columbia Sewage Treatment Plant

Item	Average 1956	1957
Sewage flow (mgd)	159.1	162.8
Equivalent pop.	1,138,000	1,109,000
Grit:		
Removed (cu ft/mg)	2.3	2.5
Solids (%)	68.4	66.0
Volatile (%)	18.8	21.7
Suspended solids:		
Raw sewage (ppm)	190	189
Effluent (ppm)	94	89
Reduction (%)	50.5	52.9
BOD:		
Raw sewage (ppm)	160	147
Effluent (ppm)	117	109
Reduction (%)	26.9	25.9
Raw sludge:		
Removed (dry, lb/day)	123,100	134,800
Solids (%)	7.6	7.1
Volatile (%)	68.7	70.5
Grease (%)	22.2	21.8
Scum:		
Removed (gpd)	17,634	17,600
Solids (%)	11.1	9.5
Volatile (%)	90.7	89.5
Sludge digestion:		
Volatile solids added daily (dry, lb)	87,740	97,500
Digested sludge removed (gpd)	76,000	64,000
pH, digested sludge	7.2	7.0
Temperature, digested sludge (°F)	83.6	86.6
Grease, digested sludge solids (%)	8.4	9.4
Supernatant, suspended solids (ppm)	26,400	19,500
Sludge gas:		
Total (1,000 cu ft/day)	692	556
Used (1,000 cu ft/day)	500	421
Wasted (1,000 cu ft/day)	192	135
Unit produced (cu ft/lb vol. solids)	7.9	5.7
Btu, gross (per cu ft)	642.0	634.1
Btu, net (per cu ft)	590.6	581.8
Methane (%)	59.6	58.8
Carbon dioxide (%)	33.7	35.0
Elutriated sludge:		
Solids (%)	9.0	8.1
Volatile solids (%)	45.0	48.3
Ratio, wash water to sludge volume	2.8	2.4
Alkalinity, digested sludge (ppm)	3,450	2,950
Alkalinity, elutriated sludge (ppm)	620	640
Effective wash-water ratio	4.6	3.6
Elutriate:		
Suspended solids (ppm)	1,040	1,460
Alkalinity (ppm)	1,330	1,350
BOD (ppm)	484	1,010
Sludge dewatering:		
Dewatering time, total (days)	229	169
Filter hours, total	4,884.6	3,919.2
Cake produced, total (tons, wet)	20,240	16,698
Solids in cake (%)	30.5	30.7
Dry solids in cake, total (tons)	6,180.5	5,128.9
Yield of solids (lb/sq ft/hr, dry)	5.06	5.23
$FeCl_3$	4.68	4.81
Suspended solids in filtrate (ppm)	80	72

ing and treating the sewage by primary treatment averaged $9.01 per million gallons in 1956 and $12.59 per million gallons in 1957. The pumping charges only were $2.32 and $2.45 per million gallons during 1956 and 1957, respectively.

Operating data for the fiscal years 1956 and 1957 are summarized in Table II.

EFFECTS OF FORCED DRAFT VENTILATION AT A MUNICIPAL SEWAGE TREATMENT PLANT

By G. A. Rhame, C. R. Beall, Charles Doyle, and Emory Williams

South Carolina Water Pollution Control Authority

Several sewage treatment plants in South Carolina have trickling filters designed to operate under forced draft ventilation. The ventilation wells, generally two per filter, are equipped with exhaust fans designed to increase the circulation of air through the filter. The filter underdrain system is relied upon to bring air from all parts of the filter to the blower.

It is believed that original work on this system was done with reversible fans, so that natural air circulation could be augmented. Reversibility would permit blowing air down the ventilation wells during cold weather and exhausting air from the wells during periods when air temperatures exceed sewage temperatures. Apparently all plants in South Carolina are built to exhaust air from the filter wells only.

Since fan installations add to the cost of trickling filters, and conversation with plant operators had raised the question of their advantages, it was decided to investigate the problem. A quick survey showed only one plant suitable for study purposes.

Of all the sewage treatment plants in South Carolina, only the one at Florence has two identical filters designed for blown air. It had the additional advantage that, through a generous agreement with the city management, a field laboratory of the Water Pollution Control Authority is located in the control building of the plant. The plant is relatively new and operates at much less than design load. Sewage is mostly domestic.

The Florence treatment plant consists of the following units, in order of flow-through plan: two primary clarifiers in parallel, one filter dosing tank, two trickling filters with forced draft ventilation (multiple arm), and two final clarifiers in parallel. Separate sludge digestion facilities are provided.

Through the cooperation of the personnel of the Florence sewage treatment plant, one filter was operated with fans off and ventilation hatch covers open (Filter A) and the other with fans on (Filter B). Field work was done by personnel of the Florence laboratory of the South Carolina Water Pollution Control Authority. Between March 3 and October 30, 1957, thirty-three sets of samples were examined.

Procedure

Since the physical arrangement assured reasonably equal loads on each filter, grab samples of the filter effluents were taken at nearly the same time, mostly before 1:00 PM. Samples were taken as often as the regular laboratory work schedule permitted.

Readings were made of the following items for each filter: temperature,

TABLE I.—Summary of Test Results

Date 1957	Temp (°C)		DO (ppm)		Eff. BOD (ppm)		Settled Eff. BOD (ppm)		Settleable Solids (ml/l)		Eff. pH		Eff. Alk. (ppm)	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
3/18	—	—	—	—	30	47	—	—	2.0	6.0	7.2	7.2	121	123
19	—	—	—	—	40	31	—	—	6.0	3.0	7.4	7.4	134	128
20	—	—	—	—	57	76	—	—	4.0	2.0	7.4	7.4	116	130
25	16.5	16.5	7.5	7.7	53	39	40	30	1.0	0.5	7.2	7.1	46	44
26	18.0	18.0	5.9	6.8	193	321	152	76	7.5	5.0	7.1	7.2	68	66
27	16.5	16.5	8.0	8.3	66	84	59	81	2.5	1.5	7.2	7.3	62	64
28	17.0	17.0	6.4	6.3	213	268	124	164	6.5	14.0	7.2	7.1	74	87
4/2	19.5	19.5	4.4	6.2	121	91	88	71	6.0	2.0	7.3	7.2	90	94
4	20.0	21.5	2.1	4.4	449	132	100	128	18.0	14.0	7.2	7.3	104	100
5	20.5	21.0	3.7	5.0	194	117	112	76	17.0	4.0	7.2	7.3	108	111
17	27.0	27.0	3.2	0.8	204	369	62	135	15.0	40+	7.4	7.4	142	150
6/21	28.0	27.5	3.7	2.5	156	345	72	90	2.5	22.0	7.5	7.5	184	206
24	26.0	26.0	4.3	0.0	346	790+	43	80	4.0	40+	7.5	7.4	138	152
28	22.0	22.0	5.2	5.3	69	107	39	24	0.8	2.5	7.5	7.5	138	182
7/4	27.0	27.0	4.5	4.1	60	345	40	80	3.5	30.0	7.5	7.4	156	150
5	27.0	27.0	5.1	3.1	82	118	43	37	3.0	19.0	7.6	7.5	138	144
25	27.0	27.0	5.3	2.9	111	247	61	97	2.0	16.0	7.6	7.6	132	146
26	26.5	26.5	3.7	1.7	186	324	108	108	7.5	31.0	7.7	7.7	198	202
31	27.5	27.5	3.1	3.5	106	129	81	89	14.0	5.5	7.5	7.7	196	184
8/2	28.0	28.0	3.5	4.6	96	181	76	79	3.5	2.5	7.4	7.4	128	130
29	27.0	27.0	4.9	5.6	66	82	55	43	3.5	2.5	7.5	7.6	126	128
30	28.0	27.0	4.8	5.7	99	65	53	52	3.0	1.5	7.4	7.4	138	140
9/10	28.0	28.0	6.1	7.6	75	98	58	68	1.5	1.5	7.3	7.4	102	122
16	27.0	27.0	4.0	5.2	182	102	47	120	10.0	3.0	7.5	7.5	120	108
26	25.0	25.0	5.4	4.0	56	52	48	54	0.6	0.5	7.4	7.5	118	164
10/3	25.5	25.5	4.5	5.3	85	82	69	68	0.5	0.5	7.7	7.7	152	154
21	20.0	20.0	4.0	7.0	386	45	217	47	29.0	1.0	7.4	7.6	130	124
24	21.0	21.0	4.5	5.1	50	68	64	84	3.0	3.0	7.4	7.5	124	122
25	22.0	22.0	4.7	4.8	88	60	57	58	4.0	4.0	7.3	7.3	124	102
28	22.0	22.0	4.5	5.4	132	121	106	138	2.0	1.5	7.5	7.6	184	168
29	20.0	20.0	5.2	6.2	71	78	63	64	1.0	1.5	7.5	7.6	140	144
30	22.0	22.0	5.8	6.0	64	83	60	74	0.5	0.5	7.6	7.6	162	162
31	22.0	21.5	5.7	5.2	56	62	54	63	0.8	0.8	7.6	7.7	168	168
Avg	23.5	23.5	4.8	4.9	128	156	75	79	5.6	8.6	7.4	7.4	129	133
No. of lower values observed	—	—	20	10	21	12	20	10	11	16	—	—	—	—

DO, BOD before and after settling in Imhoff cones (1 hr), settleable solids, pH before settling, methyl orange alkalinity before settling, and ammonia, nitrite, and nitrate nitrogen on the last seven sets of samples. The data are tabulated in Tables I and II.

Results

Temperature

Effluent from Filter A, the natural draft filter, had an average temperature of 23.5°C, ranging from 16.5 to 28.0°C. The effluent from Filter B—the forced draft filter—had the same average temperature and range. On a few occasions there was as much as 0.5°C difference between effluents. Temperatures were recorded to the nearest 0.5°C.

Dissolved Oxygen

Dissolved oxygen as measured in the filter effluents showed no great

divergence. Averages for Filters A and B were 4.8 and 4.9 ppm, respectively. Minimums were 2.1 ppm for A and zero for B. Maximums were 8.0 ppm for A and 8.3 ppm for B. DO in A was higher than in B in two-thirds of the sets of measurements. High and low values for both filters occurred during the first half of the tests. During late summer and the fall variations were generally quite small. Such close agreement was a little unexpected.

BOD Before Settling

Results of these tests were somewhat of a surprise, as the average of all data for Filter A was 128 ppm, while Filter B averaged 156 ppm. Since, as mentioned earlier, all tests were made on grab samples the results are extremely variable, showing a range from 30 to 447 ppm for A, and 31 to over 790 ppm for B. The up-and-down variations of the two filters did not occur on the same days, but both had lowest average results in the late summer. Filter A showed lower results on 21 days; Filter B on 12.

BOD After Settling

A portion of each sample was settled in an Imhoff cone and BOD tests were run on the top liquid. This was done on 30 testing days. Here, the average results for the two filters were very close—75 and 79 ppm for A and B, respectively. Results for A were considerably more erratic than for B, as shown by the fact that, although averages are close together, Filter A showed lower BOD results in 20 sets of tests, while B had lower results in 10 sets.

The range of values for Filter A was from 39 to 217 ppm. For Filter B the range was from 24 to 164 ppm.

Settleable Solids

Settleable solids in the filter effluents were determined as part of the investigation of the effects of settling on BOD. Results showed extreme variations, particularly in the effluent from B. Averages for 32 sets of analyses were 5.6 ml/l for Filter A and 8.6 ml/l for Filter B. Range for A was 0.5 to 29 ml/l; for Filter B, 0.5 to 40+ ml/l. High values first appeared in March for B and in April for A. Filter A had lower results on 11 occasions; Filter B, on 16 occasions; and 6 were identical.

pH

Results of this test on straight filter effluent showed much less variation between filters than for other tests previously described. Lowest values were found in the spring and the highest in midsummer. A tendency to taper off in the fall was observed. The pH ranged from 7.1 to 7.7 and averaged 7.4.

Methyl Orange Alkalinity

Average results were 129 ppm for A and 133 ppm for B. Lowest results for both filters were obtained in the last half of March. Range for Filter A was from 46 to 198 ppm and for Filter B, 44 to 206 ppm.

Ammonia, Nitrite, and Nitrate Nitrogen

Nitrite and nitrate were quite low for both filters, but no significant trend developed. Testing was con-

TABLE II.—Nitrogen in Filter Effluent

Date Oct. 1957	Ammonia N (ppm)		Nitrite N (ppm)		Nitrate N (ppm)	
	A	B	A	B	A	B
21	5+	5+	—	—	—	—
24	9	14	0.40	0.50	—	—
25	14	12	0.20	0.35	none	none
28	22	20	0.20	0.25	none	none
29	14	12	0.15	0.20	none	none
30	16	18	0.10	0.15	0.40	0.25
31	20	20	0.10	0.15	0.40	0.35

fined to the latter half of October. Results are given in Table II.

Summary

Attempts were made to derive the trends of the analytical data by the usual graphs and statistical treatment. It soon became apparent that these procedures had little advantage over visual comparison of the tabulated data.

In general, it appears that the Filter B unloads itself more freely and the effluent suspended solids have better settleability. The result is that the effect of high BOD in the filter effluent, which is generally associated with a high volume of settleable solids, is cancelled out by better settleability. Average values for the BOD of settled effluent from both filters were nearly identical. However, for temperatures above 22°C the BOD of the settled effluent from B was higher. At these same temperatures the per cent BOD removal by settling was greater for Filter B effluent. Temperature and seasonal effects on efficiencies are compared in Tables III and IV.

Other parameters of performance show no significant variation between the filters. It was reported that Filter B sometimes showed more green growths on its surface, particularly near the fans.

TABLE III.—Distribution of BOD Data and Settling Efficiencies According to Temperature

Temp (°C)	Effl. BOD (ppm)		Settled Effl. BOD (ppm)		BOD Removal by Settling (%)	
	A	B	A	B	A	B
16.5–17	136	145	86	110	37	24
18	193	321	152	76	21	76
19.5–20	215	78	107	75	50	8
20.5–21	122	92	88	80	27	13
22	88	93	68	74	23	20
24.5–25	121	188	78	81	36	95
25.5–26	216	438	49	74	77	83
27	117	210	51	85	52	59
27.5–28	106	126	73	81	31	36

TABLE IV.—Distribution of BOD Data by Months

1957	Effl. BOD (ppm)		Settled Effl. BOD (ppm)		BOD Removal by Settling (%)	
	A	B	A	B	A	B
Mar.	132	178	94	88	29	51
Apr.	271	113	100	92	63	19
June	194	403	56	82	71	80
July	109	232	67	82	39	65
Aug.	87	109	62	58	30	46
Sept.	104	84	51	81	51	4
Oct.	125	77	92	76	26	1

Conclusions

1. Use of forced draft ventilation in the trickling filters of this municipal sewage treatment plant appears to have little effect on effluent quality.
2. Trends of data on BOD and settleable solids, plus observations at the plant, suggest that forced draft ventilation could be of value if improved air distribution could be arranged.
3. Forced draft ventilation, as used in Florence, may have advantages where sewage temperature is high.

Acknowledgments

The authors wish to express their appreciation for the helpful cooperation of Aaron Marshall, City Manager; Ralph Sebrell, Chief Operator; and T. S. Cox, Operator, all of the city of Florence, S. C. Appreciation is also expressed to W. T. Linton, Executive Director, South Carolina Water Pollution Control Authority, for his interest and support of this investigation.

DIGESTER CLEANING EXPERIENCE *

By Anthony E. Bell

Chief Operator, Sewage Treatment Plant, Santa Cruz, Calif.

Sludge digestion units at Santa Cruz consist of two 55-ft diameter flat-bottomed digesters. The primary has a fixed concrete cover with a 3-ft manhole above the raw sludge inlet and a 5-ft opening where the propeller-type mixer is mounted. There are no ground level or side access manholes. Piping is such that tank overflow can be taken from the 12-ft level or from the bottom.

Digester Operation

The sludge mixer does a good job keeping the tank contents homogeneous, even though there is no draft tube or other means of sludge circulation. The propeller is submerged into the sludge several feet in the center of the tank, drawing scum from the surface and forcing it to circulate toward the bottom. The mixer is operated almost continuously and it is believed that this is a prime reason why no noticeable scum problems have developed. Plant personnel have theorized that since the sludge in a quiescent digester stratifies and settles out rapidly, gas pockets at the bottom are inevitable. When they break free they probably carry some sludge up to the top of the tank to add to the scum blanket. The gas is trapped against the scum, adding to the buoyancy of the blanket and raising it higher to become drier. Effort is made to keep the tank contents moving all of the time, releasing the gas. Although the theory may be wrong, there has been no scum problem, and gas production is much smoother and steadier with the mixer going continuously. Because the digester overflow goes to the secondary tank, there is no concern with its solids content. This is one obvious advantage which stage digestion has over a single digester.

In addition to mixing, the digester is carefully fed and slugging is avoided. Assuming 24,000 gal of sludge goes to the digester daily, it is preferred to pump 1,000 gal every hour than 2,000 gal every 2 hr. It is considered bad practice to stretch the pumping cycle to 4,000 gal every 4 hr. Since sludge production rarely goes above 25,000 gpd, the digester is not being overloaded or force fed. The absence of scum troubles also may be attributed to this practice.

Grit

There are no grit removal facilities at Santa Cruz, so the grit that settles out in the treatment unit and the flotation vacuator goes to the primary digester along with the sludge. Santa Cruz is a seashore community with a fine popular beach and everyone carries some sand away with him. Consequently the plant eventually gets it. In addition, many of the lines are old and in poor condition. Infiltration is very high and grit and silt find their way into the system quite readily.

The presence of grit had been observed from the first few weeks of operation when a sand deposit was noticed in the raw sludge inlet box and drifts of sand banked against the walls of the aeration unit ahead of the vacuator. So a record was kept of the buildup of grit inside the digester by plumbing and sampling the bottom at three points. Under the sludge inlet a mound began to grow, and in five years it was 5 ft high, although the sampling rod could still be pushed to the tank bottom. The center of the tank re-

* Presented at the 1957 Annual Meeting, California Sewage and Industrial Wastes Assn.; San Diego, Calif.; May 1–4, 1957.

mained clear, and after seven years only a slight resistance to the plumb rod was felt in the last foot of depth. At the side opposite the sludge inlet, washed samples taken from 3 ft of heavy sludge found in the seventh year contained only a small amount of fine silt. The big mound was almost all sand, grit, buttons, and miscellaneous material. At the rate of accumulation it was estimated that there would be a comfortable 10- or 12-yr period before loss of capacity might call for cleaning out the grit.

Unexpectedly, along came the winter of 1955 with the December storms and flood. The San Lorenzo River overflowed its banks and covered some streets to a depth of 5 ft, leaving mud and silt everywhere. The plant was by-passed during the flood, of course, but the collection lines got loaded with silt, and when treatment was resumed, they unloaded into the plant at a frightful rate. The sludge valve grated and ground when turned, and the line to the bottom of the vacuator would plug solid in less than an hour. It all went into the primary digester and the buildup of grit increased so fast that the 10 or 12 years of grace shrank to nothing. The pile under the inlet rose to 14 ft, and was expected daily to seal off the inlet.

Digester Grit Removal

As a result of the flood, the city was granted federal funds to repair public facilities. Of these funds, the sum of $2,500 was allocated to the cost of cleaning the digester. When bids were called to do the job, only one was submitted, and it was for over $10,000. The city council promptly rejected it and set a new date.

Meanwhile the sewer lines were being cleaned, and although most of the debris was being removed at the manholes, the influent to the plant was heavy with sand and silt all the time.

Contractor Confidence

A contractor, engaged to raise manholes to the new grade created by flood-deposited silt in some unpaved streets of town, heard of the digester job and visited the sewage treatment plant. After looking at the drawings of the digester and being assured that the tank could be drained to the 5-ft level by gravity to the plant grounds, he proceeded to prepare a bid. It was pointed out that there probably was a good 5 or 6 ft of grit in the tank which was not likely to go out with the liquid.

The contractor explained that he would hook a pump to the end of the line outside and wash the sand to it inside. When he got down to a couple of feet he planned to put a flexible suction line on the inside and go around and vacuum up the rest.

The specifications called for removal of the solids through the top of the digester to the plant grounds. This part was waived to permit removal in a workmanlike manner. No time limit was set for completion of the job and this was regretted later. The contractor's bid was $3,300.

Plant Preparation

As soon as the sewer cleaning was done part of the raw sludge was diverted to the secondary unit. Gradually the feed was increased until in several weeks all the sludge was going to this unit. This change was undertaken slowly for several good reasons. It did not seem wise to convert the secondary digester into a primary digester abruptly. As it was, the secondary was upset for awhile, giving a poor supernatant. Further, it was intended to let the primary rest for as long as possible. Thus, for 30 days it was left to work itself out, insuring that no raw or partially digested sludge would be left to cause a nuisance when removed to the plant grounds. The mixer was operated all of the time. This was done with the thought that

it would help reduce whatever scum was present.

The Cleanup

On July 23 the contractor arrived with an air compressor, a piston pump, and three men. A bulldozer was used to throw up 3-ft dikes around the large area of the plant grounds to form a sludge-holding lagoon. Then the 3-ft manhole cover was removed and the sludge discharge line was opened.

The digested sludge and liquor jetted from the discharge line in an arc 6 ft long and boiled into the lagoon for several hours. When it stopped, a few jolts with the sludge pump started it going again, but from then on it needed urging all the time. The pump was hooked to the end of the line, and the washing of the grit to the line inside was started.

The compressor fed air into the digester until the atmosphere registered safe on the explosion meter. Then an inspection was made to see the extent of the problem. With planks laid on the scum layer, which was about 2 ft thick, it was possible to walk halfway around the tank. The deposit was 12 ft deep near the access manhole and sloped off to about 4 ft at the far side. As the mass drained it became firmer and firmer, until at the end it could be sheared off almost vertically.

For three weeks the contractor washed and prodded the mass, trying to pump it out. All that was removed was the scum layer and the heavy sludge. Remaining was an average depth of about 5 ft of firm, black grit that would have to be mucked out. A winch and bucket arrangement, with a dead lift, was decided on.

The End

On October 12, 71 calendar days after starting the job, the crew finished and left. Plant personnel had kept a rough account of the work and estimated that about 2,500 man-hours had been expended and almost a million gallons of water used. The contractor claimed a loss of more than $4,000.

TRICKLING FILTER PERFORMANCE *

I. MECHANICSBURG, PENNSYLVANIA

By Lawrence M. Moyer

Superintendent, Sewage Treatment Plant, Mechanicsburg, Pa.

Treatment Units

The Mechanicsburg, Pa., sewage treatment plant was designed for an average flow of 0.64 mgd and a peak of 1.40 mgd. Operation started on September 13, 1950. Major treatment units include primary and secondary clarifiers, primary and secondary filters, a separate sludge digester, sludge-drying beds, and a chlorine contact tank. A flow diagram is shown in Figure 1.

Both the primary and secondary filters are 60 ft in diameter, with a rock filter media 4 ft 6 in. deep. The filters can be conveniently flooded to control filter flies by closing the sluice gates in the effluent lines.

Primary Filter Loading

Composite 24-hr samples were taken for a three-day period beginning on Sunday. Sunday is a light day, Monday a heavy day, and Tuesday an average day. The average daily flow for these three days was 0.370 mgd. Results of the tests showed an average raw sewage BOD of 297 ppm, a primary clarifier effluent BOD of 66 ppm, and a final clarifier effluent BOD of

* Presented at the 1957 Annual Meeting, Pennsylvania Sewage and Industrial Wastes Assn.; University Park, Pa.; Aug. 28–30, 1957.

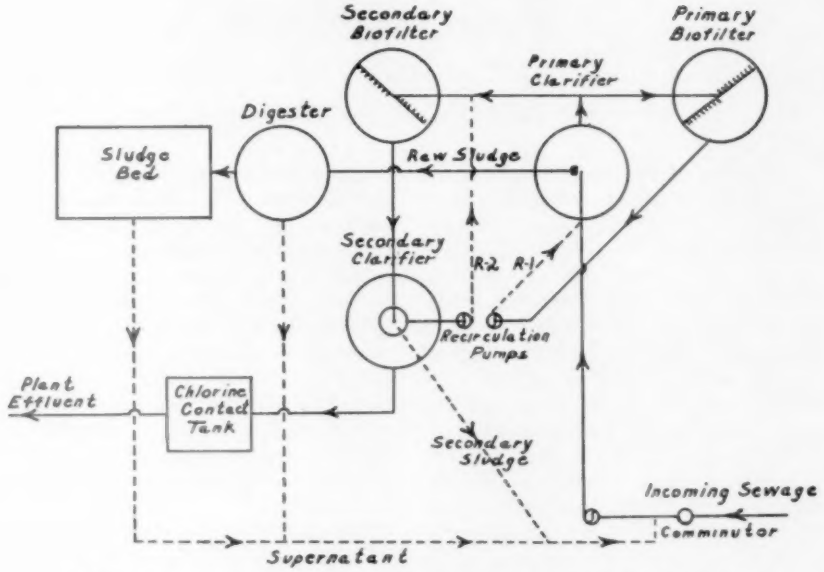

FIGURE 1.—Flow diagram of Mechanicsburg, Pa., sewage treatment plant.

13 ppm. Over-all performance showed a BOD reduction of 95.6 per cent.

The average suspended solids in the raw sewage was 319 ppm. The primary clarifier effluent contained 93 ppm and the final clarifier effluent contained 20 ppm. The average suspended solids reduction was 93.7 per cent. Average daily flow to the primary filter during the tests was 0.72 mgd. The BOD load was 393 lb per day. This flow placed a hydraulic load on the filter of 11.1 mgd/acre and a BOD load of 0.83 lb per cu yd per day. Recirculation from the primary filter to the primary clarifier is at a rate of 0.72 mgd.

Secondary Filter Loading

The secondary filter is equipped with a four-arm high-rate distributor fed by a 14-in. line from a recirculation manhole which receives part of the primary clarifier effluent and the recirculation from the secondary clarifier. Secondary recirculation is pumped at a constant rate of 0.72 mgd. The total flow to the secondary filter averaged 1.09 mgd. The BOD load was 279 lb per day, including the BOD in the recirculated flow. The hydraulic load on the filter was 16.5 mgd/acre and the BOD load was 0.60 lb per cu yd per day. The BOD removal of the secondary filter and final clarifier averaged 57 per cent.

Problems and Maintenance

Problems have been limited to an occasional slight ponding of the secondary filter. A fire hose is used to break up the surface growths causing ponding. Filter flies have been observed, mostly on the primary filter, but have not been a nuisance.

Filter maintenance consists of routine cleaning of orifices and distributors once each week with a high-pressure water hose. Oil in the turntables is checked monthly and drained and refilled twice annually. Once each year the distributors are dismantled and thoroughly cleaned and wire brushed. A primer is applied and the units are finished with a coat of aluminum paint.

II. EASTON, PENNSYLVANIA

By T. W. Greenlund *

Operations Engineer, Glace and Glace, Inc., Harrisburg, Pa.

The City of Easton, Pa., placed its new sewage treatment plant into operation in the fall of 1952. This new plant, designed to provide complete treatment to a combination of domestic and industrial wastes, replaced a primary treatment plant constructed in 1926. The original plant had become heavily overloaded, and offered only token treatment in the years immediately preceding its abandonment.

The design capacity of the new plant is 5 mgd, based on a future population of 50,000 and a per capita contribution of 100 gpd. All sewage reaching the plant must be pumped from the site of the abandoned plant, a distance of approximately 3,000 ft. The primary portion of the treatment process consists of comminution, grit removal, and primary settling in two 100-ft diameter clarifiers. Secondary treatment is provided by two high-rate trickling filters operated in parallel. Each filter is 160 ft in diameter, with an average stone depth of 4.4 ft. The filters are followed by two secondary clarifiers, identical in size to the primary tanks. Recirculation with a total design ratio of 2:1 is provided through the return of secondary underflow to the primary clarifiers and secondary launder flow to the filters. A flow diagram is shown in Figure 1.

Two 65-ft diameter digesters provide multi-stage digestion. The primary unit is equipped with a fiixed cover and mixing apparatus, and the secondary unit has a floating gas holder. Digested sludge is dried on 19 open drying beds, each 20 by 109 ft. A 200-sq ft vacuum filter was installed in

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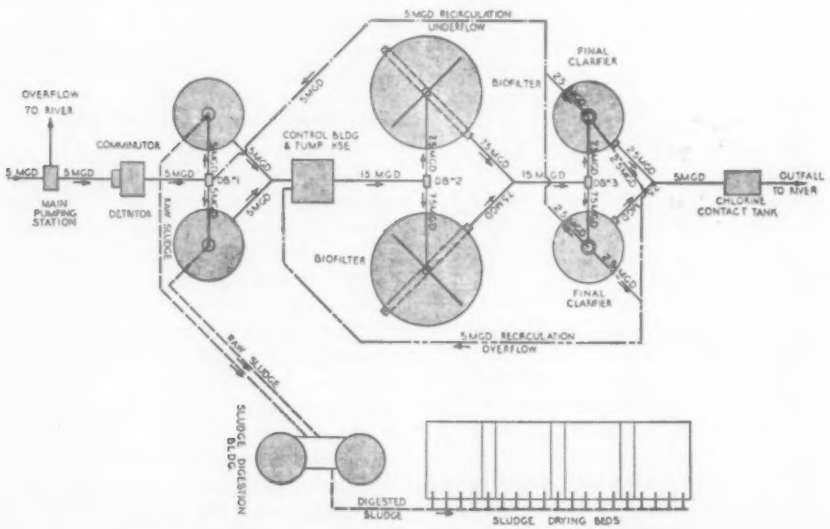


FIGURE 1.—Flow diagram of Easton, Pa., sewage treatment plant.

TABLE I.—Average Annual Sewage Strength

Year	BOD (ppm)			Suspended Solids (ppm)		
	Raw	Final	Efficiency (%)	Raw	Final	Efficiency (%)
1954	468	39	91.5	381	38	90.0
1955	474	40	91.6	459	51	88.9
1956	458	34	92.6	369	49	86.7
1957	512	26	94.9	379	34	91.0

the fall of 1957 to supplement the drying beds and provide greater flexibility for sludge drying.

Prior to the construction of the new treatment plant, a detailed laboratory analysis was conducted to establish the strength of the waste for design criteria. Results of the tests indicated an average BOD of 382 ppm for raw sewage and a suspended solids content of 402 ppm. A BOD of 350 ppm was chosen for design purposes. Although this represented a decrease from the test results it actually provided for an increase in the per capita loading from 0.22 to 0.27 lb per day. In actual practice the waste at the new treatment plant has consistently shown a higher strength than the original analysis indicated. A summation of these average values for the past 3½ years is given in Table I, together with the average percentage removals.

As a check on design theory, and to determine the actual efficiencies of the principal units, a special series of analyses were made in June 1957 on the effluent from the primary clarifiers and the filter effluent. The regular testing program was continued at the same time so that the other analytical data were available during this period. This program included BOD and suspended solids tests on the influent, set-

TABLE II.—Test Results

Date (June 1957)	BOD (ppm)				Date (June 1957)	Suspended Solids (ppm)			
	Raw Sewage	Primary Effl.	Filter Effl.	Plant Effl.		Raw Sewage	Primary Effl.	Filter Effl.	Plant Effl.
4	288	160	18	16	3	472	78	54	19
11	367	140	21	21	10	478	76	52	21
26	339	111	40	7	26	195	63	41	8
Avg	331	137	26	15	Avg	382	72	49	16

TABLE III.—Efficiencies

Date (June 1957)	BOD Removal (%)				Date (June 1957)	Suspended Solids Removal (%)			
	Across Primary Clarifiers	Across Filters	Across Filters and Sec. Clar.	Total		Across Primary Clarifiers	Across Filters	Across Filters and Sec. Clar.	Total
4	44.4	88.8	90.0	94.4	3	83.5	30.8	75.6	96.0
11	61.9	85.0	85.0	94.3	10	84.1	31.6	72.4	95.6
26	67.3	64.0	93.7	97.9	26	79.0	34.9	87.3	95.9
Avg.	58.6	81.0	89.1	95.8	Avg	81.2	31.9	77.8	95.8

TABLE IV.—Comparison of Calculated Filter and Secondary Clarifier Efficiencies

Date (June 1957)	Flow (mgd)	Calculated Efficiencies (%)		Observed Efficiency (%)
		NRC	Upper Miss.	
4	2.10	87.2	87.5	90.0
11	2.59	86.7	87.5	85.0
26	2.79	87.5	87.5	93.7
Avg	2.46	87.1	87.5	89.1

tled sewage, filter effluent, and final effluent. A summary of these test results is presented in Tables II and III.

The original basis of design anticipated a 35 per cent reduction in BOD through the primary clarifiers, and a 77.7 per cent filter efficiency. The theoretical efficiency of the total treatment process was calculated to be 87 per cent. These results were based on a flow of 5 mgd, a raw sewage strength of 350 ppm, and a total recirculation ratio of 2:1. During the test period, the average 24-hr flow at the treatment plant was 2.46 mgd. At present, the recirculation is set to return a total flow of about 6.25 mgd, this provides a recirculation ratio of approximately 2.5:1.

Although the efficiency of the secondary treatment process (Table III) is higher than the original design anticipated, theoretical calculations of the expected efficiency on the days of the tests indicate that the filters should be operating at approximately the per cent removals observed.

Calculated Filter Efficiency

Filter efficiencies were computed using the National Research Council (NRC) (1) and the Tentative Standards (Upper Mississippi) (2) formulas. The NRC formula is represented as follows:

$$E = \frac{100}{1 + 0.0085\sqrt{\frac{W}{VF}}} \quad \ldots\ldots (1)$$

in which

E = Efficiency of single-stage filter and clarifier (%);

W = BOD (lb);

V = Filter volume (acre-ft);

F = Recirculation factor.

The Upper Mississippi formula is:

$$E = \frac{100(R + 1)}{R + 1.5} \quad \ldots\ldots (2)$$

in which

E = Efficiency of a single-stage filter and secondary clarifier (%);

R = Total recirculation ratio.

Results of the application of each equation on each day of the test program are indicated in Table IV. Because the value R remains essentially constant in the range of flows observed during the test program, the Upper Mississippi formula produces a constant result. The NRC equation (Eq. 1) gives results which vary in general with the observed results.

The data in Table I indicate the over-all plant efficiency at Easton, Pa., has been satisfactory during the past three years. Although the test data available for analysis of the various treatment units are quite limited, it appears that the special test results are substantially in line with past results, as far as plant efficiencies are concerned. The high over-all efficiencies observed during the special testing pro-

gram were apparently brought about by better than average suspended solids and BOD removals in the primary clarifiers, and by a slightly better than average secondary efficiency. The reported efficiencies for the secondary treatment process agree closely with theoretical calculations of expected efficiency, when actual waste flows and strengths are considered.

References

1. NRC Subcommittee. "Sewage Treatment at Military Installations." *Sewage Works Jour.*, **18**, 5, 970 (Sept. 1946).
2. "Standards for Sewage Works, Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, and Wisconsin." Upper Mississippi River Board of Public Health Engineers and Great Lakes Board of Public Health Engineers, May 1952 (partially revised July 1954).

III. NORTH EAST, PENNSYLVANIA

By John K. Hallenburg

Sanitary Engineer, Hill and Hill Engineers, North East, Pa.

The trickling filter plant serving the Borough of North East, Pa., has had a growing problem for many years. Located within this borough of 5,000 people are four fruit-processing plants and one milk plant. All of these plants, with the exception of the Welch Grape Juice Company, discharge their industrial wastes to the municipal sewers.

The original treatment plant was built in 1914 for a population of 2,500. By 1935 the population had increased to about 3,500 and the fruit-processing plants were beginning to expand. In view of these increases, the plant was expanded to provide treatment for a population equivalent to 6,000. No further enlargement of the plant was made until 1957. In the 10-yr period beginning shortly after the 1935 addition to the treatment plant was completed, the fruit-processing plants began a rapid expansion which more than tripled their production. By 1948 the industrial wastes received during the processing season were seven times greater than the capacity of the plant.

Industrial Wastes

In 1949 a complete survey was made of the entire waste treatment system. During the fruit season the treatment plant, designed for 6,000 people, was receiving wastes with an average population equivalent load of approximately 40,000 and peaks as high as 66,000. The average flow, however, was equal to that from a population of only 5,500. The fruit season begins about the first of July with the processing of cherries, reaches a peak around the last of September when both tomatoes and grapes are processed, and ends the first of November. The BOD of the raw wastes during the season goes as high as 3,000 ppm and seldom drops below 1,000 ppm.

Filter Efficiency

The treatment plant consisted of primary settling tanks, a fixed-nozzle standard-rate trickling filter, and an inadequate secondary settling tank having a 25-min detention period. The filter was designed on the basis of 250 to 500 lb of BOD per acre-ft. It was treating approximately 3,000 lb per acre-ft. After the filter first began to receive the heavy cherry season load it removed an average of 91 per cent of the applied BOD, with occasional removals as high as 98 per cent. However, as these heavy waste loads continued during the fruit-processing season the amount of BOD removed decreased. During the tomato pack, the filter averaged 85 per cent BOD removal, and during the grape harvest

the efficiency decreased to an average of only 67 per cent.

After the fruit-processing plants finish pressing grapes they usually shut down for a two- to four-week period. Following the shutdown they begin the bottling process and jam and jelly making. This short rest period between packs seems to be all the filter needs to completely recover. Although the loads during the winter and spring are not as high as during the fruit-processing season, the waste still has about 700 to 900 ppm of BOD. With this loading the filter returns to its high performance.

Since the survey was made in 1949, studies of filter performance under these extreme loads have continued. Furthermore, studies were made on a pilot plant constructed at the Welch Grape Juice Company. This pilot plant consisted of settling tanks and two high-rate filters that could be used either singly, in series, or in parallel. These filters were loaded up to 45 lb of BOD per cubic yard. The hydraulic loadings were varied from that of a standard-rate to that of a high-rate filter.

These studies revealed that the filter, operating either under high-rate or standard-rate conditions, accounted for nearly all of the BOD removal. The fruit-processing wastes contain only 10 to 15 per cent suspended solids; therefore, only a small percentage of the BOD is removed in the primary settling tanks. The only factor that materially affected the filter performance was the pH of the wastes. If one of the large fruit plants failed to lime its wastes for a few hours, the discharge of wastes with a pH of 4 to 5 substantially reduced the treatment efficiency for about two days. The fruit wastes are naturally acid and for this reason it is required that the processing plants lime their wastes. As an added precaution, an automatic pH control system was installed at the treatment plant.

The borough's standard-rate filter, even though it was not receiving the hydraulic loadings of a high-rate filter and was being dosed intermittently, behaved as a high-rate filter. That is, it continually discharged a light floc rather than the periodic unloading usually associated with a standard-rate filter.

The high-rate pilot filters performed best when loaded at a rate of loading between 2 and 4 lb of BOD per cubic yard. The high-rate filters in series did not show an increase in BOD removal until the loadings were less than a total of 2 lb per cubic yard for both filters. There appeared to be a sharp drop in BOD removal for loadings between 5 and 6 lb per cubic yard.

Conclusion

Using the results of these studies, a waste treatment plant was designed and constructed for the Welch Grape Juice Company. Additions also were made to the North East treatment plant. As yet these plants have not operated for a complete fruit-processing season, and performance data are incomplete.

At the North East treatment plant a high-rate filter was installed ahead of the existing standard-rate filter. It is expected that the high-rate filter will remove a large portion of the BOD in solution before the flow reaches the standard-rate filter. In both the North East and Welch Grape Juice Company treatment plants, the settling capacity is concentrated in the secondary units because of the greater conversion of dissolved solids to suspended solids by the filters.

Although other types of treatment were studied, only the trickling filter was capable of withstanding the shock loads, high organic content, and pH variations of the wastes.

TIPS AND QUIPS

New Materials

A new family of thermoplastic resins —the polycarbonates—possesses toughness, high impact strength, heat resistance, and dimensional stability that may offer possibilities for use as replacements for metals and ceramic materials for molded parts.

Flammable Liquid Containers

The American Standards Association has a standard safety color code for marking physical hazards and the identification of certain equipment in which the following statement appears: "Safety cans or other portable containers of flammable liquids having a flash point at or below 80°F (open cup tester), excluding shipping containers, shall be painted red with some additional visible identification, either in the form of a yellow band around the can or the name of the contents conspicuously stenciled or painted on the can in yellow."

If a number of different flammable liquids are handled in one department of a plant, identifying the contents by distinct lettering would be more desirable to prevent mixing. It would also be desirable to stencil the following information on all portable containers for flammable liquids:

1. For flammable liquids having a flash point 20°F or below: DANGER!—EXTREMELY FLAMMABLE—Keep Away From Heat, Sparks, and Open Flame. Keep Closed When Not In Use.

2. For flammable liquids having a flash point of 20° to 80°F: WARNING!—FLAMMABLE—Keep Away From Heat, Sparks, and Open Flame. Keep Closed When Not In Use.

3. For flammable liquid having a flash point of 80° to 150°F: CAUTION!—COMBUSTIBLE—Keep Away From Heat and Open Flame. Keep Closed When Not In Use.

Laboratory Acid Pump

An all polyethylene acid pump is now available to ease the handling of corrosive acids in the laboratory. Figure 1 shows the pump in action.

FIGURE 1.—Polyethylene acid pump for use with 5-pint acid bottles.

The pump screws onto any standard 5-pint acid bottle. Attached to the pump are a siphon, a spout, and a 4-oz squeeze bottle. The unbreakable unit delivers acid at the rate of 1,000 ml/min with urging from the squeeze bottle. A relief valve button is provided to stop the flow and the spout is said to be drip-proof. Fisher Scientific Company, 419 Fisher Bldg., Pittsburgh 19, Pa.

It is research that gives the American economy its characteristic surge.

CRAWFORD H. GREENEWALT

Industry Pollution Control Expenditures

In a report of the Washington Pollution Control Commission for the last seven months of 1957 it is stated that improvements and additions which involve the control of pollution by pulp and paper mills in the State of Washington, as outlined in this report, cost approximately $24 million. Of that amount, approximately 25 per cent yields direct pollution control benefits from the installation of fiber recovery equipment, sanitary sewage facilities, etc. The remaining 75 per cent involved expenditures for additional projects, such as heat and chemical recovery equipment, which are classed as secondary pollution abatement benefits.

Laboratory Stirring

A new laboratory stirring unit is available incorporating several design improvements: (a) narrower (2¼ in. wide) head-on silhouette to fit tight spaces, (b) sealed gear head (no lubricant loss), (c) universal support rod, (d) three-wire cord, and (e) two chucks on a hollow spindle. Variable speed and high torque are features of this stirrer, which will operate on intermittent heavy duty. Bulletin 270 from Eberbach Corporation, P. O. Box 63, Ann Arbor, Mich., provides further details.

Operator Training

The recently chartered Sacramento Area Section of the California SIWA has made arrangements with the Sacramento Junior College to give a course in sewage and waste disposal. The objectives are to upgrade employees working in the field and provide background training for new employees. For additional information write to Bill Heckey, 3248 D St., Sacramento, Calif.

Paint

An outdoor water-based latex paint is being tested across the country by Union Carbide to determine its resistance to varying climatic conditions. The paint, known as WC-130, has so far indicated good performance on brick, concrete blocks, stucco, concrete, and cement-asbestos shingles. The paint is expected to wear much longer than the standard three years for conventional paint jobs.

A heat-resistant aluminum paint claimed to withstand temperatures of 1700°F is now on the market. The paint, known as Heat-Rem H-170, is recommended for hot ducts, traps, stacks, vents, engine heads, mufflers, etc. Information can be obtained by writing to Speco, Inc., 7308 Associate Ave., Cleveland 9, Ohio.

BOD Bottle Seals

George Martin, Federation Past President, writes from Green Bay, Wis., that, for those laboratory people who have been having trouble maintaining a water seal on BOD bottles with the shallow sealing lip, there is a very inexpensive and satisfactory way of overcoming this. Just cover the bottle stoppers with one-ounce waxed medicine cups. These can be purchased from Dixie Cup Company which designates them as their No. 101, 1-oz, Dixie Medicine Cups. They are also sold by the American Hospital Supply Corporation, Evanston, Ill., which designates them as Tomac Med-A-Cup No. 458. Most local drug or paper supply houses should be able to supply them at about $0.85 per 100.

One-ounce plastic cups are also available, but they cost more and are not as serviceable as the waxed paper cups.

Power from Gas

For power generation, it is reported that 24 cu ft of 600- to 700-Btu gas will produce 1 kwhr.

Editorial

THIRTY YEARS AGO IN THE JOURNAL

With this issue of SEWAGE AND INDUSTRIAL WASTES, we salute those responsible for the first number, published in October 1928. Certainly any publication beginning its fourth decade may take careful note of its past, present, and future.

Volume I, No. 1, is available in only a limited number of libraries because time has proved the print order definitely conservative. Certainly no one could have been expected to envision the demand from a Federation membership roster which has grown much greater than even the optimists of the time hoped.

The development and growth of the Journal was by its nature synonymous with Federation expansion. From the original five Member Associations with 273 members, these thirty years have seen the embryo organization enlarge to 42 Member Associations serving virtually the whole civilized world. The original subscription list has since increased thirty-fold to about 9,500, including nearly 1,400 non-member subscribers. The monthly number printed has exceeded 10,000 throughout 1958.

On such an anniversary, it is certainly fitting to note with appreciation the generous contribution made by Dr. Floyd W. Mohlman, the first Editor of SEWAGE WORKS JOURNAL. Serving without compensation he molded the original editorial policies and had the full responsibility of editorial production from 1928 through 1943. At that time, W. H. "Pete" Wisely became Editor but Dr. Mohlman continued his service to the Federation as Advisory Editor, a position he still holds. The Journal's reputation as an authoritative reference attests to the superlative service of these two editors.

The Journal aims, as expressed editorially in the first number, remain essentially the same though great advance in our knowledge has been made since 1928. The closing sentences of the first editorial are quoted for reference.

"As to the editorial policy, the Editor is particularly sympathetic to the needs of the operator for short, practical, helpful articles on sewage works operation. The ultimate goal of engineers, research workers, and operators is to make it possible to design and operate a sewage treatment plant to the limit of efficiency of the selected process, without forced shutdowns, odors, or complaints. The lamentable neglect and poor operation of small treatment works is partly caused by the inability to bring to the operator a realization of his responsibilities, and the necessity for considering the sewage works as a biological factory which requires constant attention and supervision. THIS JOURNAL will attempt to bring to the operator in a practical way the fruits of research, the experiences of his fellow workmen in meeting and solving difficulties, and news of what is being done in other countries to advance the science of sewage treatment."

This policy has been followed and broadened as the changes of time have required, but devotion to water pollution control through proper wastewater treatment remains our ultimate goal.

R.E.F.

News and Notes

Of Persons and Activities in the Wastewater Field

Marvin L. Granstrom, formerly Associate Professor of Sanitary Engineering at the University of North Carolina, has accepted the position of Chairman of the Department of Civil Engineering at Rutgers University. **W. G. Snow,** former Chairman of the Department, will continue on the staff at Rutgers.

William S. Wise, Director of the Connecticut Water Resources Commission and a member of the New England Water Pollution Control Commission, has recently been appointed to the 10-man Federal Water Pollution Control Advisory Board by President Eisenhower.

Professor **Harold E. Babbitt** has been appointed Visiting Professor of Sanitary Engineering at the University of Missouri in Columbia. Professor Babbitt is in retirement as Head of the Department of Sanitary Engineering at the University of Illinois.

Norman E. Jackson has recently returned to Washington, D. C., where he has assumed the position of Assistant to the Director of Sanitary Engineering for the District of Columbia Government.

James Corbalis, Jr., has been named Engineer-Director of the Fairfax County (Va.) Water Authority. He leaves his post as Engineer-Director of the Alexandria, Va., Sanitation Authority to assume this newly-created position.

Samuel W. Shaefer, former Superintendent of Operations and Maintenance for the Alexandria Sanitation Authority, has been named to fill the position vacated by Mr. Corbalis.

Harry G. Hanson, Director of the Public Health Service's Robert A. Taft Sanitary Engineering Center in Cincinnati, has been promoted to Assistant Surgeon General in the USPHS. He has been Director of the Taft Center since 1954.

Thomas G. Glenn, Jr., has been appointed Director and Chief Engineer of the Interstate Sanitation Commission (New York, New Jersey, and Connecticut). He fills the vacancy created by the death of **Seth G. Hess.**

Earnest Boyce, Chairman of the Civil Engineering Department at the University of Michigan and Professor of Public Health Engineering, has just returned from a sabbatical leave spent at several South Pacific Islands as a Sanitary Engineer Consultant for WHO.

Dr. Max Suter recently retired as Principal Engineer of the Illinois State Water Survey. He has been associated with the Survey since 1936.

A. Stanford Johnson has been promoted to Sanitary Engineer of the Madison, Wis., plant of Oscar Mayer and Company. He succeeds **John Eckstein** who recently resigned.

W. M. Gross has been elected Vice President of Infilco Inc. and will represent the company's interests on the east coast.

Frank J. McKee has transferred to the Research and Development Division of National Dairy Products Corporation, Glenview, Ill. He formerly was Sanitary Engineer with Kraft Foods Division.

Grant Pettit, Industrial Waste Engineer, Armco Steel Corporation, has been cited by the Ohio River Valley Water Sanitation Commission for his "valued service in the crusade for clean streams." He was one of three members of the steel industry to receive ORSANCO's newly-established Certificate of Appreciation.

Ivan Maxwell Glace died at his home on September 6, 1958. He founded the firm of Glace and Glace, Inc., Consulting Engineers, Harrisburg, Pa., in 1935 and served as its President until his retirement in 1957.

L. L. Hedgepeth, Technical Consultant for American Cyanamid Company and longtime leader in the industrial wastes field, died recently. "Hedge" was a 1950 winner of the Bedell Award and has been active on a number of Federation Committees.

George D. Bers has resigned as President of Chicago Pump Co.

Reviews and Abstracts*

Determination of Oil in Refinery Effluent Waters. By J. B. Rather, Jr. *Anal. Chem.*, 30, 36 (1958).

The committee tested several new methods against the presently accepted procedures of the American Petroleum Institute. The results indicate that the infrared procedure is the best of those tested on an over-all basis of comparison. For the infrared determination the oil is extracted from an acidified, salted solution into carbon tetrachloride and compared against standards of known oil concentration.

R. S. Ingols

Chromatographic Identification and Determination of Organic Acids in Water. By H. F. Mueller, T. E. Larson, and W. J. Lennarz. *Anal. Chem.*, 30, 41 (1958).

By using a small volume of sample with various amounts of butyl alcohol, it is possible to identify many simple organic acids and synthetic detergent radicals. The procedure is not complicated and is quantitative for the acids included in the reference chromatogram.

R. S. Ingols

The Agricultural Value of Sewage Sludge and Town Refuse. By G. E. G. Mattingly. *Proc. Inst. Civil Eng. (Brit.)*, 8, 414 (1957).

This paper summarizes the results of field experiments carried out in Great Britain since 1940. The effects of sewage sludges, pulverized town refuse, screened dust and composts of town refuses with sewage sludge, and straw with sewage sludge have been investigated.

Details of the organic matter, nitrogen (total and inorganic), phosphorus, and potassium contents of the various wastes and composts used, are given.

Sewage sludges supply slowly available nitrogen and phosphorus but very little potassium (most of which is lost in the sewage effluent). Composts of sewage sludge and straw are easier to handle than sewage sludge, which if above 50 per cent moisture, is expensive to transport and difficult to work into the soil. Composts are potassium-deficient and do not supply as much nitrogen to the crop as sewage sludge, unless stored carefully for 6 to 12 months.

Pulverized refuse and screened dust are both potassium-deficient and give much lower crop yields than equivalent amounts of farmyard manure. Composts of sewage sludge and town refuse are also low in potassium, but supply useful amounts of nitrogen to the crops. Organic manures made from town wastes generally give higher yields when used with inorganic fertilizers.

D. Jenkins

Note on the Stream-Flow Effect upon the Course of Self-Purification of Streams. By A. Nejedlý and J. Pelz. *Vodní Hospodárstvi* (Czech.), No. 4, 1 (1957).

The authors show that there is a difference in the rate of the BOD reaction as expressed by the value of the coefficient of deoxygenation, under laboratory bottle and flowing stream conditions, as a function of longitudinal mixing. They define the degree of longitudinal mixing as the slope of a line formed by plotting the dispersions of individual detention curves, expressed in terms of standard deviations, against the abscissae of their center of gravities (the mean time of flow), and present data obtained under stream flow and laboratory conditions. Other laboratory data verify the assumed effect of longitudinal mixing upon the rate of the BOD reaction. Very

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N.W., Washington 16, D. C.

different values of the deoxygenation coefficients have been observed for wastes of the same original composition, but subject to longitudinal mixing. The results presented are of a preliminary nature, and much work needs to be done, but the authors feel that a correlation between the value of longitudinal mixing and the ratio of the deoxygenation coefficient values as determined under laboratory conditions vs. those found under stream-flow conditions is needed to define the course of self-purification in streams.

CONRAD P. STRAUB

BOOKS, REPORTS PAMPHLETS

Hoover's Water Supply and Treatment. National Lime Assn., Washington, D. C. 8th Ed., 221 pp. Price $2.12, postpaid (1957).

The revised and enlarged edition of this well-known water supply book was prepared by M. L. Riehl, Mahoning Valley Sanitary District, Youngstown, Ohio. Many of the latest practices have been included.

A Clean Potomac River in the Washington Metropolitan Area. BY ABEL WOLMAN, JOHN C. GEYER, AND EDWIN E. PYATT. Interstate Comm. on the Potomac River Basin, Washington, D. C. (1957).

U. S. Research Reactors. U. S. Atomic Energy Comm., Washington, D. C. (1957).

Describes (with illustrations) the research reactors in operation or under construction.

Industrial Wastes and Conservation. Pennsylvania State Chamber of Commerce, Harrisburg, Pa. (1957).

Presents the paper given at the 1957 Pennsylvania Clean Streams Conf., April, 1957.

The Meaning, Significance, and Expression of Commonly Measured Water Quality Criteria and Potential Pollutants. BY HOWARD B. BROWN. Bull. No. 58, Engrg. Exp. Sta., Louisiana State University, Baton Rouge 3, La. (1957).

Radiation Safety and Major Activities in the Atomic Energy Programs, July–December, 1956. U. S. Govt. Printing Off., Washington, D. C. 396 pp. Price $1.25 (1957).

Section 1 is the 21st Semiannual Report of the Atomic Energy Commission on major activities in the atomic energy programs, and Section 2 is a special report on radiation safety, including radioactive wastes.

Development of Design Criteria for Waste Stabilization Ponds. BY E. R. HERMANN AND E. F. GLOYNA, Dept. of Civil Engineering, Univ. of Texas, Austin, Texas (1957).

The final technical report on waste stabilization ponds prepared under a research contract with the U. S. Atomic Energy Commission.

Water Pollution Study—San Joaquin River Watershed. Central Valley Regional Water Pollution Control Board, Sacramento, Calif. (1957).

Proceedings of the 1957 Air and Water Pollution Abatement Conference. Manufacturing Chemists' Assn., Inc., Washington, D. C. 131 pp. Price $2.00 (1957).

Contains 14 papers on pollution abatement presented in April 1957.

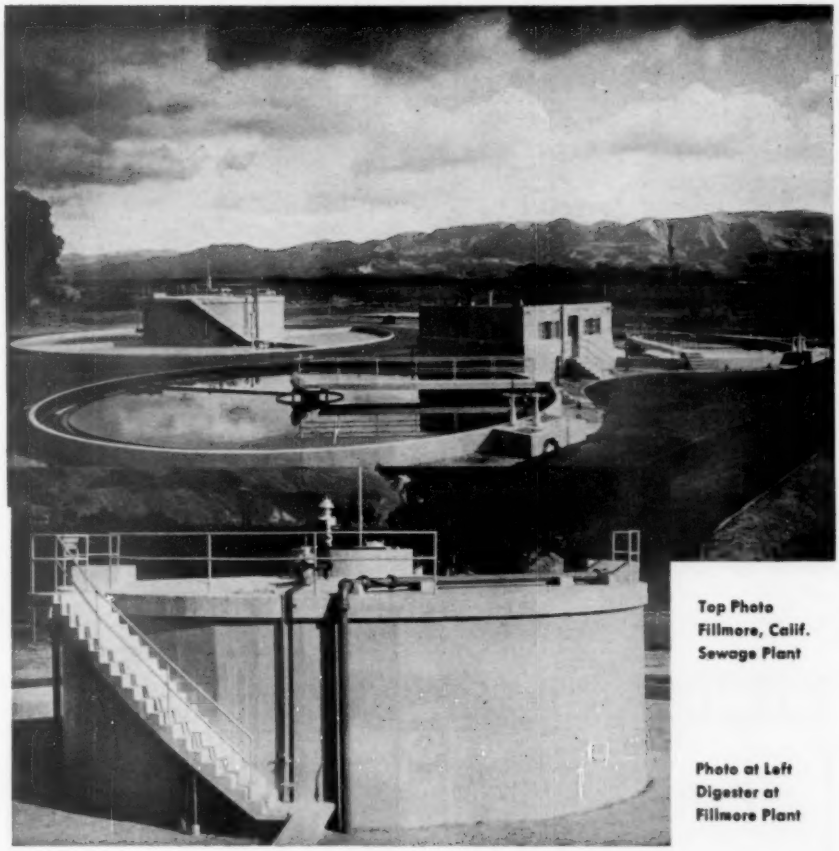
Ninth Annual Report, Housing and Home Finance Agency, 1955. Housing and Home Finance Agency, Washington, D. C. (1956).

Reports on the activities of the various administrations under this agency. Of particular note is the Community Facilities Administration and the public facility loans, including sewage treatment.

Metropolitan Communities: A Bibliography. Public Administration Service, 1313 East 60th St., Chicago 37, Ill. (1956).

A special working bibliography with special emphasis upon government and politics and prepared by Government Affairs Foundation, Inc.

Indiana Water Resources. Indiana Water Resources Study Committee, Indiana State Board of Health, Indianapolis, Ind. (1956).



Top Photo
Fillmore, Calif.
Sewage Plant

Photo at Left
Digester at
Fillmore Plant

Varec Equipment helps Fillmore, Calif. meet its Sewage Problem

Fillmore faced a common problem of many Southern California cities, – a booming population that over-taxed the sewage system.

The solution was a compact, modern digester system that is efficient and attractive. To protect this fine plant against fire and explosion, and regulate the volatile sewage gas for smooth operation, VAREC SEWAGE GAS CONTROL AND SAFETY DEVICES are on the job.

Over 18 years of experience in controlling sewage gases has made Varec one of the leaders in the field.

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Proceedings of Member Associations

OHIO SEWAGE AND INDUSTRIAL WASTES TREATMENT CONFERENCE

The 32nd Annual Meeting of the Ohio Sewage and Industrial Wastes Treatment Conference was held at the Commodore Perry Hotel, Toledo, Ohio, June 18–20, 1958. A total of 220 members and guests were in attendance.

The program, which was well balanced between sewage and industrial wastes, extended over three full days, with concurrent sessions being held on the second day. Among the highlights of the meeting were panel discussions on sewerage systems and oil industry efforts in pollution abatement, and a manufacturers' forum on package waste treatment plants.

The following excellent papers were presented:

"Home Garbage Grinders and Their Effects," by A. D. Caster, Principal Engineer, Mill Creek Sewage Disposal Works, Cincinnati, Ohio.

"Indian or Chief?—The Choice is Yours!", by R. E. Lawrence, Black and Veatch, Consulting Engineers, Kansas City, Mo.

"District Law for Sewage Treatment," by Paul W. Dixon, Assistant Attorney General, State of Ohio.

"The Eight Steps to the Solution of Industrial Waste Problems," by Edmund B. Besselievre, K and H Engineering Co., Toledo, Ohio.

"The Disposal of Paper Mill Wastes by Spray Irrigation," by Harold C.

(*Continued on page 420a*)

WEMCO® the INCREDIBLE Torque-Flow Pump

pumps almost everything

(what will go in will come out)

secret: recessed impeller; continuous open passage

(wear effect is negligible)

Western Machinery Company 650 Fifth St. San Francisco, California

"MN" • *The New Simplicity*
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— in Measuring Flow Through Open Flow Nozzles

The BURGESS-MANNING Type "MN" Meter

eliminates:

Stilling well and cover
Connecting pressure piping and fittings
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Sediment traps
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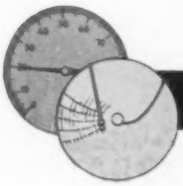
Float cable
Clear water for flushing
Space and concrete work needed for above

Here is a distinct advance in the art of measuring flow of liquid under gravity conditions. Here is accurate measurement of flow at all times. Here is a method of measurement that is free of troublesome and highly objectionable maintenance.

Think of the savings! Think of the elimination of maintenance!

Write for Burgess-Manning "MN" Meter Bulletin



BURGESS-MANNING COMPANY

Penn Instruments Division

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Koch, Weston Paper and Manufacturing Co., St. Marys, Ohio.

"Evaluation of the Blaw-Knox-Ruthner Pilot Plant Program," by J. H. Strassburger, Assistant Vice President, National Steel Corp., Pittsburgh, Pa.

"Industrial Waste Treatment Facilities, Libbey-Owens-Ford Glass Co.," by Henry W. Hauenstein and Wayne Kohn, respectively, Senior Sanitary Engineer, Finkbeiner, Pettis and Strout, Toledo, Ohio, and Chief Structural Engineer, Libbey-Owens-Ford Glass Co.

"Industrial Waste Control in Ford Motor Company," by F. J. Kallin, Chief Civil Engineer, Engineering and Planning Dept., Ford Motor Co., Dearborn, Mich.

"Toledo Sewage Treatment Plant Improvements," by A. H. Niles, Commissioner, Div. of Sewage Disposal, Bay View Park, Toledo, Ohio.

"Toledo-Lucas County Sewerage and Water Survey," by Carleton S. Finkbeiner, Finkbeiner, Pettis and Strout, Consulting Engineers, Toledo, Ohio.

"Organization and Operation of the 1957 Ohio River Pollution Survey," by J. E. McLean, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, and P. E. Langdon, Jr., Greeley and Hansen, Engineers, Chicago, Ill.

"Cuyahoga River Basin Water Inventory," by S. L. Frost, Dept. of Natural Resources, State of Ohio.

Inspection trips to the Toledo sewage treatment plant and the Sun Oil Separation and Dephenolizing plant were well attended.

FSIWA Vice-President, W. D. Hatfield, represented the Federation Headquarters and presented the Bedell Award for extraordinary personal serv-

(*Continued on page 422a*)

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PERMANENT!
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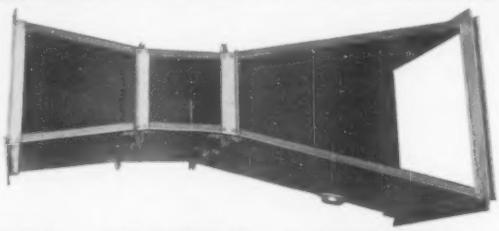

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Chemstone flume liners are made of asbestos cement material impregnated with a special asphaltic compound under pressure. It will withstand shock, vibration and is impervious to most acids, alkaline solutions and rapid temperature changes.

Saves many hours of building forms for concrete pouring and is accurate within plus or minus 1/16". Flume liners with throats 3" to 18" are furnished completely assembled for quick, easy installation. For throats 18" to 96" the liners are furnished in two sections.

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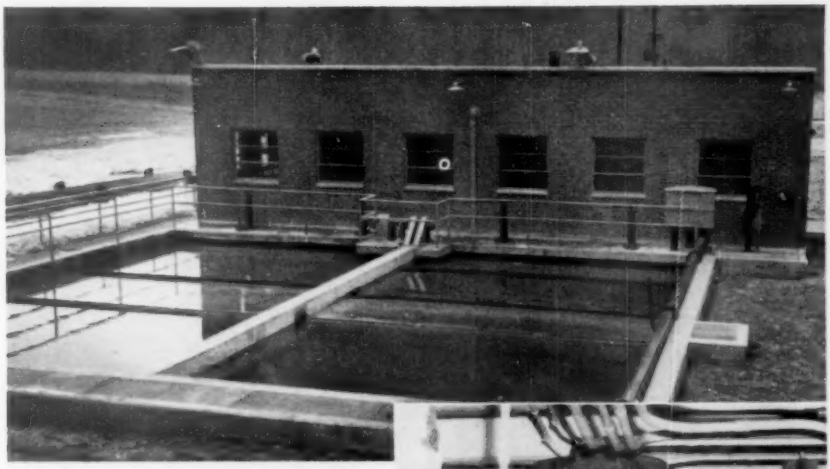
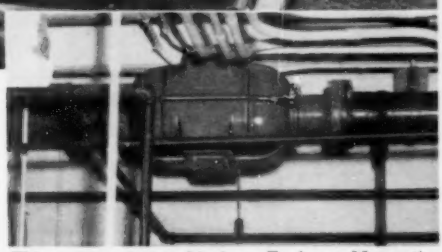


with FOXBORO MAGNETIC FLOW METER



This compact, trouble-free Foxboro Magnetic Flow Meter is installed right in the return activated sludge line at Sidney, Ohio's modern new sewage plant. There's nothing in the line to obstruct flow . . . no pressure taps or purges.

No line restrictions — no pressure taps to plug. With the Foxboro Magnetic Flow Meter there's nothing in the line to cause pile-up of solids. And you can forget about purging of pressure taps — there aren't any. Electric cable carries measurement signal to remote Dynalog* Electronic Recorder, providing a direct magnetic measurement of fluid velocity.

Get full details on this unique development in flow meters. Write for Bulletin 20-14B. The Foxboro Company, 8810 Neponset Ave., Foxboro, Mass., U. S. A.

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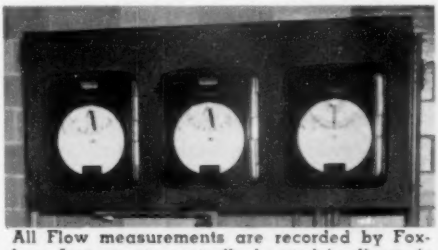

All Flow measurements are recorded by Foxboro Instruments centrally located in director's office at Sidney plant. Shown above are: (l. to r.) Air Flow Recorder with integrator: Sewage Flow Recorder with integrator: Dynalog Recorder for return activated sludge.

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Three Gruendler No. 1, Sewage Screening Shredders at the Grand Rapids Michigan Sewage Disposal Plant.

For greater dependability and minimum of attention, the Bar-Screen Shredder operation is the most modern method in Sewage Plants. Special design of the Shredder reduces rags, sticks, leaves etc., to a fine consistency for smooth operation of Sewage System.

See your Consulting Engineer for data and specifications on Gruendler Units, or Write us for **CATALOG—S.G. 10** without obligation. Contains diagrams for installation, types and sizes of Units including Shredders, Garbage Grinders, Dry Sludge Shredders, Refuse and Compost Grinding Equipment.

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ice to the Ohio Association to Carl D. McGuire, Columbus, Ohio. Due to the illness of the recipient, the award was made in absentia.

At the business meeting of the association, the following officers were elected for 1958–59:

Chairman: James E. Frook, Toledo.
1st Vice-Chairman: E. W. Petrich, Urbana.
2nd Vice-Chairman: Arthur D. Caster, Cincinnati.
Secretary-Treasurer: Cleamon E. Lay, Columbus.

CLEAMON E. LAY,
Secretary-Treasurer

ALABAMA WATER AND SEWAGE ASSOCIATION

The 1958 Annual Meeting of the Alabama Water and Sewage Association was held June 4–6, 1958, at the Alabama Polytechnic Institute of the University of Alabama, Auburn, Ala., in conjunction with the 13th Annual Short Course School. A total of about 170 persons attended the sessions.

The first two days of the meeting were devoted to classroom sessions. Three concurrent sections were conducted: two on water and one on sewage. At the general session, held on the third day, excellent papers were presented on the following subjects: lagoons for sewage treatment, instrumentation of water and sewage works, disaster procedure, the city and its employees, and ground water resources in Alabama.

FSIWA President, Kenneth S. Watson, represented the Federation Headquarters in presenting to Joseph L. Crockett, Montgomery, Ala., the Bedell Award for outstanding personal service to the Alabama Association. The Hatfield Award, for outstanding operation reports, was presented to Owen D. Waldrep of Opelika, Ala.

The following officers were elected

(*Continued on page 423a*)

Surer Gland Lubrication for Centrifugal Pumps

THE Z-F GREASE SEAL eliminates that trouble spot where shaft enters casing. Applies constant positive lubrication to packing and shaft—automatically. Excessive heat, rapid wear, leakage and scoring will dissapear as the Grease Seal supplies a constant flow of lubrication when pump starts until it stops—automatically. Many other advantages, too. Write for complete description and price. Zimmer and Francescon, Moline, Ill.

ZF

to serve in 1958–59:

President: D. R. McLemore, Phenix City.
Vice-President: A. F. Lankford, Gadsden.
Treasurer: H. R. Thacker, Auburn.
Secretary: E. J. Finell, Jr., University.

E. J. Finell, Jr.,
Secretary

IOWA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 40th Annual Meeting of the Iowa Sewage and Industrial Wastes Association was held at the Hotel Chieftain, Council Bluffs, Iowa, June 18–20, 1958. Approximately 110 men registered for the technical sessions. In addition over 20 women were in attendance and have an active auxiliary organization in operation.

Excellent papers were presented on the following subjects: fringe area sanitation problems, Missouri basin water control, source control of industrial wastes, functions of the state health department in waste disposal and water pollution, management of sewer systems and plants, sewage plant equipment, safety programs, application and maintenance of lift stations, and new developments in the field of sanitation and sewage treatment.

FSIWA President Kenneth S. Watson represented the Federation.

Elected to serve in 1958–59 were:

President: Ralph Briley, Ames.
Vice-President: D. D. Douglas, Fort Dodge.
Treasurer: Harry Boren, Marion.
Secretary: L. F. Skorczeski, Marshalltown.

L. F. Skorczeski,
Secretary

SEWAGE TREATMENT PLANT OPERATOR

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Equipment and Supply Lines

Pump Discharge Control—A new pumping system is announced that uses a wound rotor motor, water rheostat combination that matches discharge pumping rate with inflow rate. Other features are the elimination of on-off pump action, stepped pump speed, surges, and absence of moving parts.—General Services Co., Corvallis, Ore.

Density Measurement—Announcement has been made of a density system which measures and/or controls fluid density, specific gravity, per cent solids, or related quantity. This unit is applicable to liquids, slurries, and flaked, granulated, powdered, or other divided solids. Based on the principles of gamma ray transmission from a radioisotope, the system makes no physical contact with the flowing material. Measurements are independent of flow rate and pressure.—Industrial Nucleonics Corp., 1205 Chesapeake Ave., Columbus 12, Ohio.

Instrument Repair—A new factory instrument repair service is available through field offices and is described in Folder EN(6).—Leeds & Northrup Co., 4934 Stenton Ave., Philadelphia 44, Pa.

Flexible Couplings—An 8-page bulletin describes new "Sure-Flex" couplings, designed for various combinations of misalignment and end float.—Bulletin 10100, T. B. Wood's Sons Co., Chambersburg, Pa.

Plastic Pipe—Corrosion-resistant, reinforced plastic pipe is manufactured in 2- to 12-in. diameter with plain, bell-and-spigot, or flanged ends. The pipe is known as Bonstrand, is nontoxic, nonflammable, and collapse-resistant. Working pressures are 250 and 500 psi in two series of pipe. Added details are available from Amercoat Corp., 4809 Firestone Blvd., South Gate, Calif.

Digestion Equipment—Digester circulator-mixers are described in Bulletin 25-5-91. These "Gaslifters" utilize the airlift principle and operate on compressed digester gas.—Walker Process Equipment Inc., P. O. Box 266, Aurora, Ill.

Sewer Maintenance—A new device has been marketed, called the "Speedi-Chuck," for quickly connecting a string of sewer rods to their driving unit.—Flexible, Inc., 3786 Durango Ave., Los Angeles 34, Calif.

Valve Lubrication—A 19- by 24-in. three-color chart containing maintenance and lubrication information for lubricated plug values has been issued by Rockwell Manufacturing Co., Meter and Valve Division, 400 N. Lexington Ave., Pittsburgh 8, Pa.

Comminutor—An improved screen and comminutor for wastewater solids handles floating and settled solids and recirculates large solids for further pulverization.—Bulletin 5150, Infilco, Inc., P. O. Box 5033, Tucson, Ariz.

Safety Ladder—An automatic aluminum ladder leveler is used for extension or single ladders when placed on stairways or other irregular surfaces.—Anderson Architectural Steel Products, Inc., 405 N. Mechanic St., Jackson, Mich.

Filter Cloth—Information on "Lainyl" filter cloths, synthetic, chemical, heat, and abrasion-resistant materials is available from Synthetic Fertilizers and Chemicals, Inc., 511 Fifth Ave., New York 17, N. Y.

Settling Tanks—The Uniflow Settling Tank is described in detail in an 8-page folder. Featured are uniform influent distribution across the tank, uniform flow throughout the entire tank length, and uniform effluent discharge from surface.—Folder 2648, Link-Belt Co., Prudential Plaza, Chicago 1, Ill.

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FLEXIBLE INC.

3786 DURANGO AVE., LOS ANGELES 34, CALIF.
1005 SPENCERVILLE ROAD, LIMA, OHIO
351 W. JEFFERSON BLVD., DALLAS, TEXAS

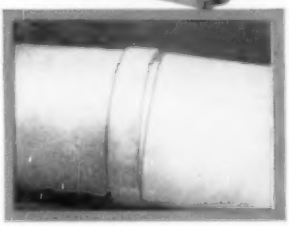
FOR YOUR MOST DEMANDING PROJECTS

...the premium pipe with the Flexible Joint!

LOCK JOINT ROLLER SUSPENSION PIPE with the FLEXIBLE JOINT RUBBER GASKET is the ideal answer to installations requiring highest quality sewer or culvert pipe and maximum protection against ground water infiltration.

This pipe, produced in diameters from 12" to 72" and in standard lengths of eight feet is manufactured by an unique process which develops unusually strong, dense concrete, highly resistant to abrasion. Its joint ends, of almost machined accuracy, are particularly adaptable to the Lock Joint Flexible Joint Rubber Gasket.

This gasket gives effective relief from infiltration into the pipeline and permits the joint to be opened up to ¾" without endangering its tightness. This feature alone adds considerably to the ease and speed with which the line can be installed.



The "Flexible Joint" gasket permits ample deflection to accommodate normal ground settlement.

Lock Joint also produces conventional machine made and cast concrete sewer and culvert pipe ranging from 6" to 120" and upward in diameter. All Lock Joint Pipe may be designed to comply with A.S.T.M., state highway or individual specifications.

LOCK JOINT PIPE CO.

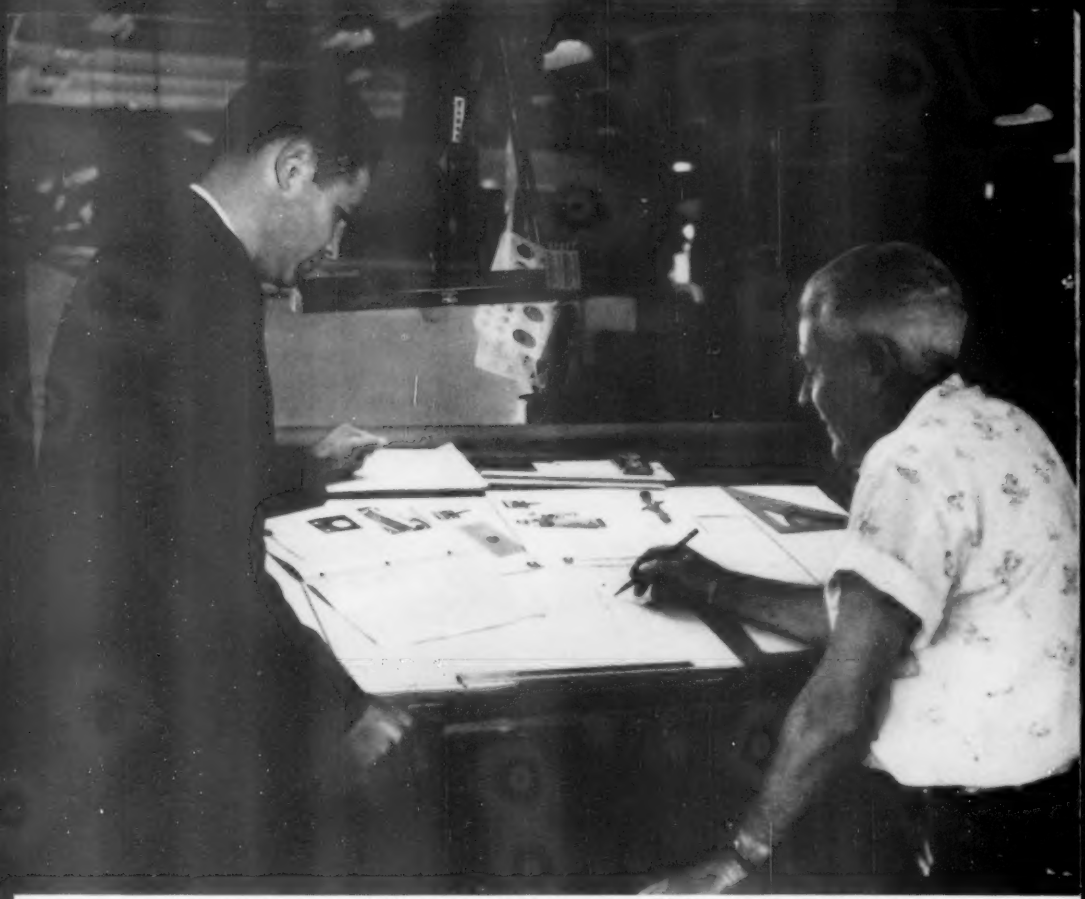
East Orange, New Jersey

Sewer and Culvert Pipe Plants:

Kenilworth, New Jersey	Valley Park, Missouri	Cheyenne, Wyoming
Hartford, Connecticut	N. Kansas City, Missouri	Casper, Wyoming
New Haven, Connecticut	Tulsa, Oklahoma	Tucumcari, New Mexico
Beloit, Wisconsin	Oklahoma City, Oklahoma	Hato Rey, Puerto Rico
Chicago, Illinois	Wichita, Kansas	Ponce, Puerto Rico
Rock Island, Illinois	Denver, Colorado	Caracas, Venezuela

Also Great Lakes Concrete Pipe Company with plants at Buffalo, N. Y. and Henrietta, N. Y.

LANCASTER PRESS, INC., LANCASTER, PA.



When you plan your new facilities, include W & T Equipment, both Chlorinators and Dry Chemical Feeders.

". . . this is where we plan to put the W & T Dry Chemical Feeders."

When you plan your new plant or the expansion of your present one, be sure to plan a place for W & T Dry Chemical Feeders as well as Chlorinators. W & T Feeders are used for every type of dry feeding problem found in water and sewage treatment plants.

W & T makes both volumetric (volume measurement) and gravimetric (weight measurement) feeders. There is a feeder for any size job, from small equipment to measure out ounces, to accurate giants capable of handling thousands of pounds per minute.

To find out more about W & T Dry Chemical Feeders, write for bulletin S-123. Or let us know the type of feeder problem you have, so we may send publications describing the W & T equipment best suited for your job.

WALLACE & TIERNAN INCORPORATED

25 MAIN STREET, BELLEVILLE 9, NEW JERSEY